FIG.1

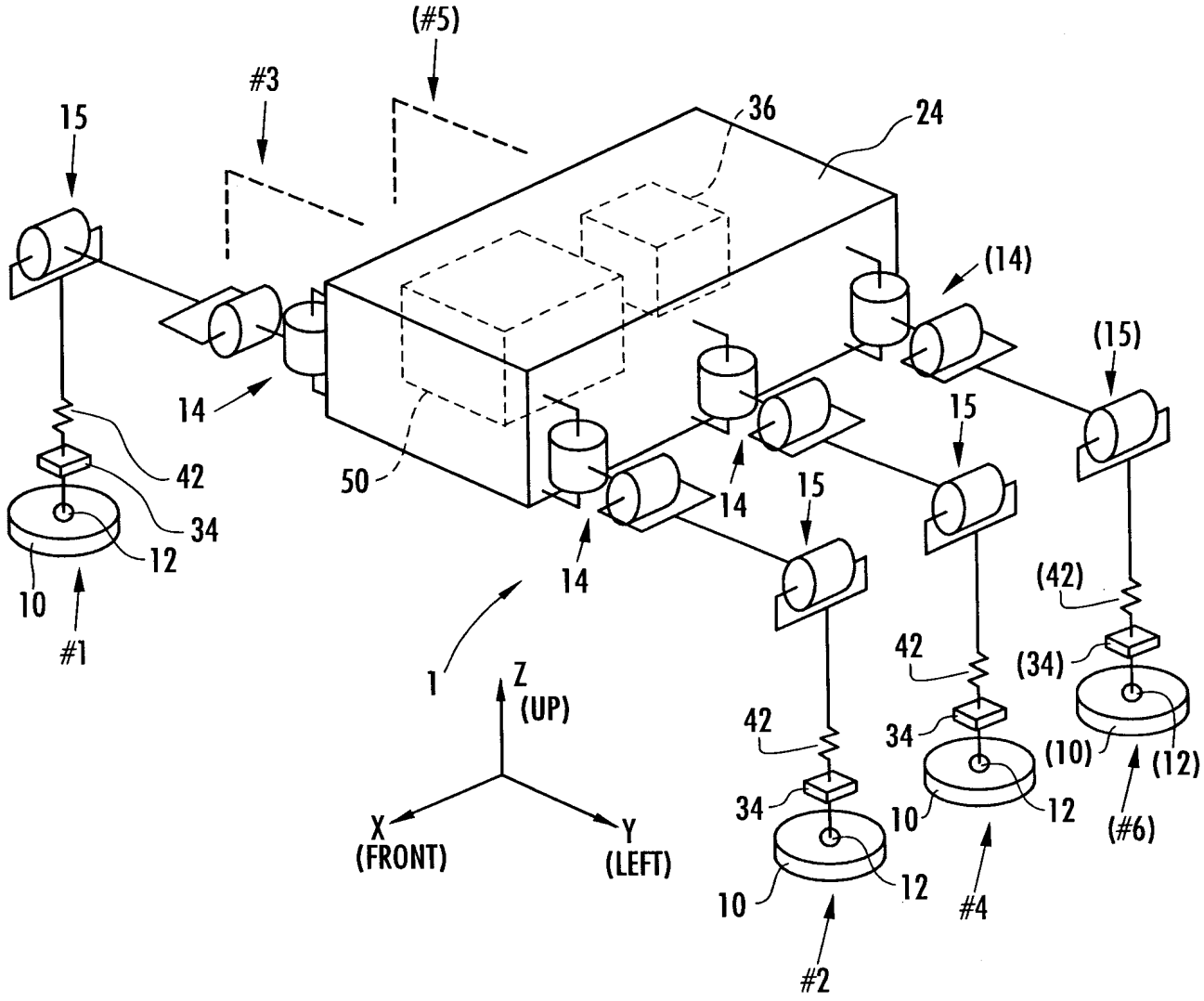

(#5)
#3
15
36
24
(14)
(15)
14
15
42
50
14
15
34
12
10
#1
14
(42)
1
42
(34)
Z
(UP)
42
34
(10)
(12)
34
10
12
(#6)
X
(FRONT)
Y
(LEFT)
10
12
#4
#2

FIG.2

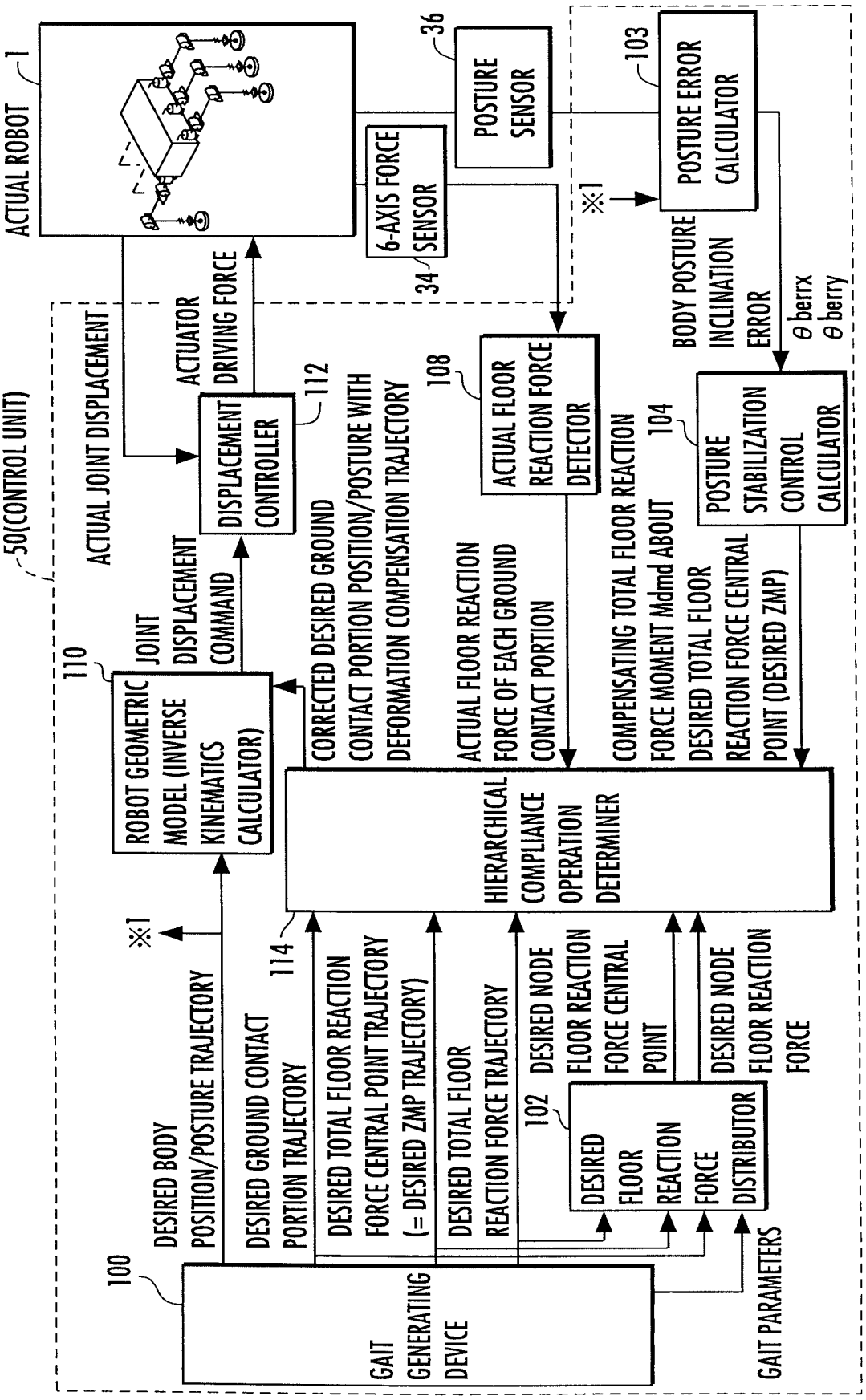

ACTUAL ROBOT
1
36
POSTURE SENSOR
6-AXIS FORCE SENSOR
34
103
POSTURE ERROR CALCULATOR
※1
50(CONTROL UNIT)
ACTUAL JOINT DISPLACEMENT
ACTUATOR DRIVING FORCE
DISPLACEMENT CONTROLLER
112
108
ACTUAL FLOOR REACTION FORCE DETECTOR
BODY POSTURE INCLINATION ERROR
θberrx
θberry
104
POSTURE STABILIZATION CONTROL CALCULATOR
110
JOINT DISPLACEMENT COMMAND
ROBOT GEOMETRIC MODEL (INVERSE KINEMATICS CALCULATOR)
CORRECTED DESIRED GROUND CONTACT PORTION POSITION/POSTURE WITH DEFORMATION COMPENSATION TRAJECTORY
ACTUAL FLOOR REACTION FORCE OF EACH GROUND CONTACT PORTION
COMPENSATING TOTAL FLOOR REACTION FORCE MOMENT Mdmd ABOUT DESIRED TOTAL FLOOR REACTION FORCE CENTRAL POINT (DESIRED ZMP)
HIERARCHICAL COMPLIANCE OPERATION DETERMINER
※1
114
DESIRED BODY POSITION/POSTURE TRAJECTORY
DESIRED GROUND CONTACT PORTION TRAJECTORY
DESIRED TOTAL FLOOR REACTION FORCE CENTRAL POINT TRAJECTORY (= DESIRED ZMP TRAJECTORY)
DESIRED TOTAL FLOOR REACTION FORCE TRAJECTORY
102
DESIRED NODE FLOOR REACTION FORCE CENTRAL POINT
DESIRED NODE FLOOR REACTION FORCE
100
GAIT GENERATING DEVICE
DESIRED FLOOR REACTION FORCE DISTRIBUTOR
GAIT PARAMETERS

FIG.3(a)

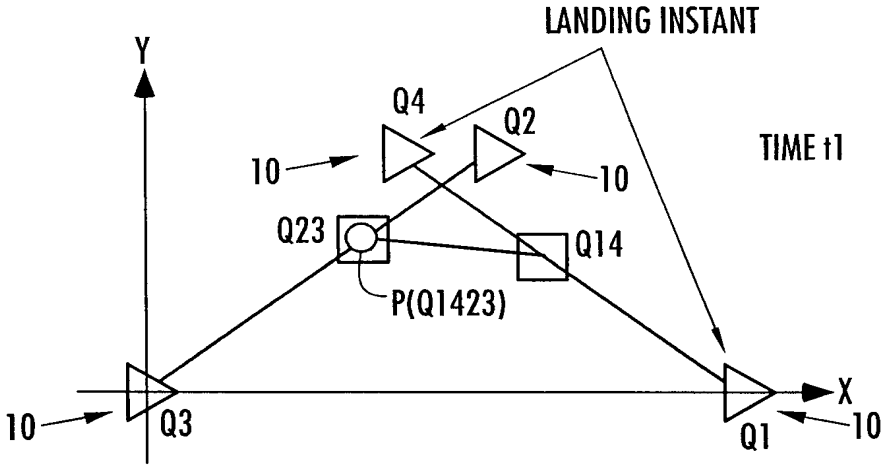


FIG.3(b)

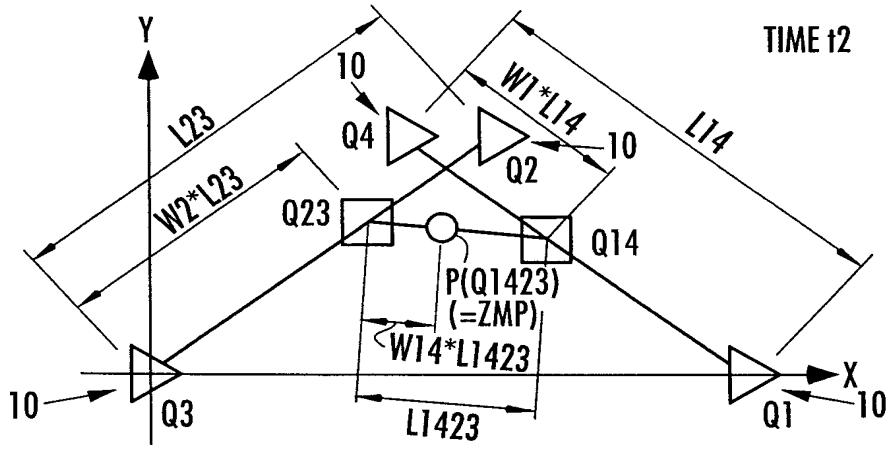
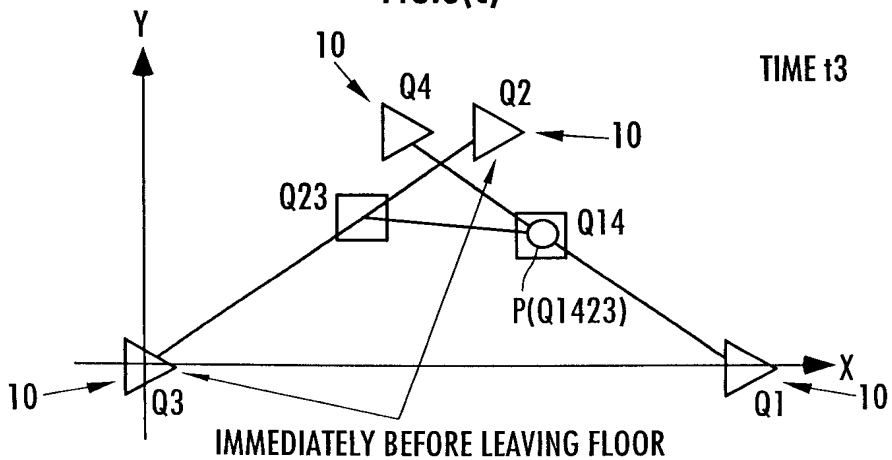


FIG.3(c)



IMMEDIATELY BEFORE LEAVING FLOOR

FIG.4(a)

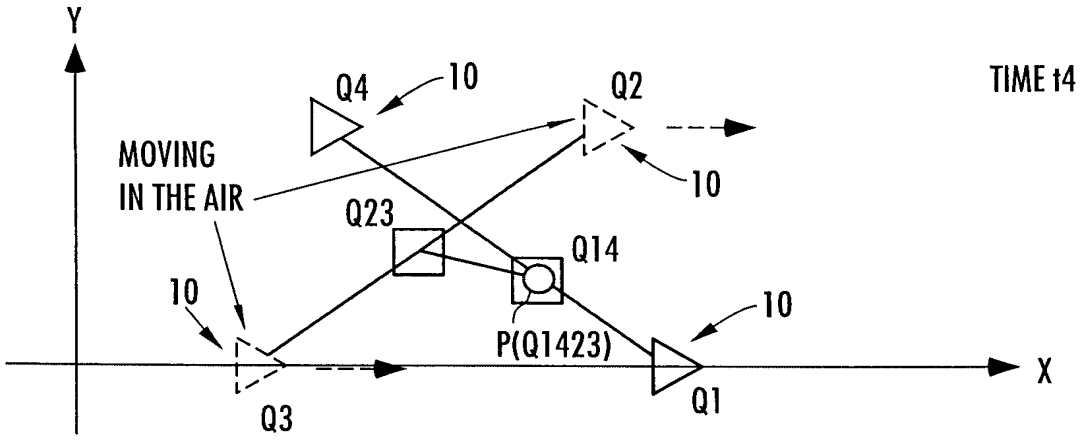


FIG.4(b)

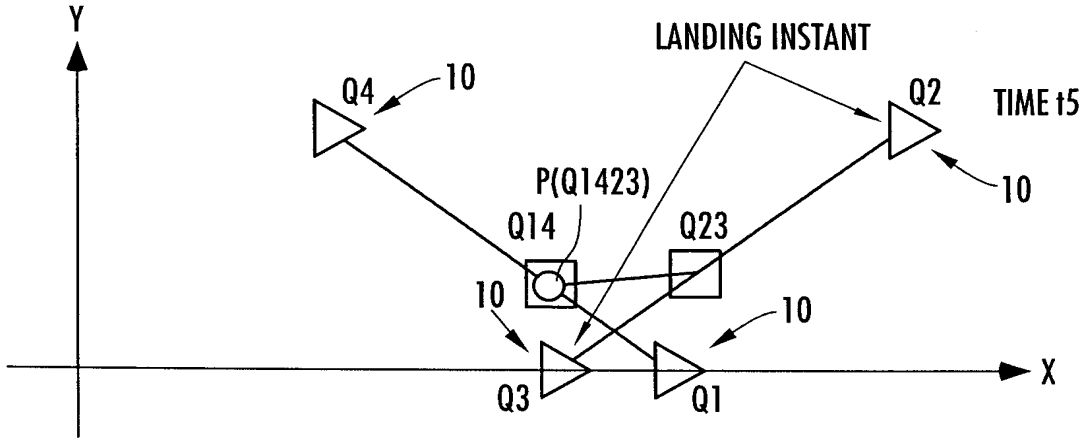


FIG.4(c)

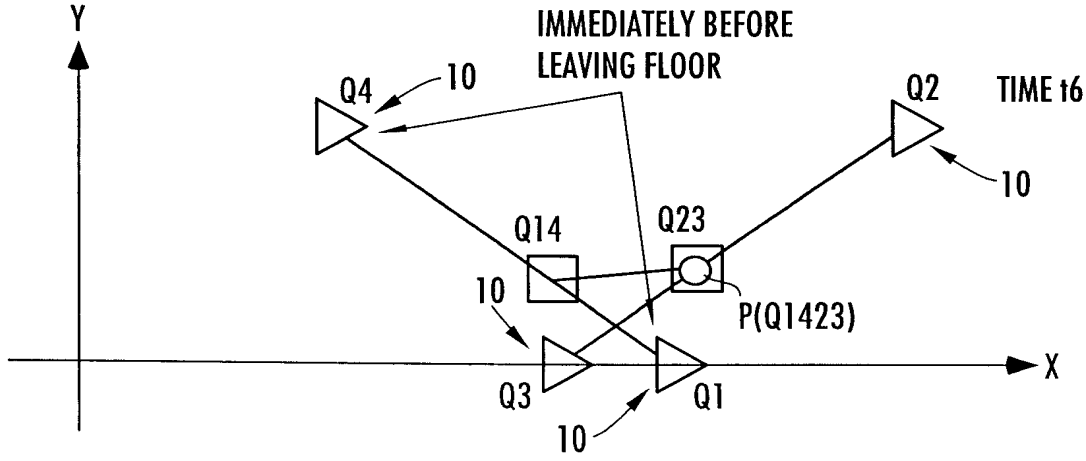


FIG.5(a)

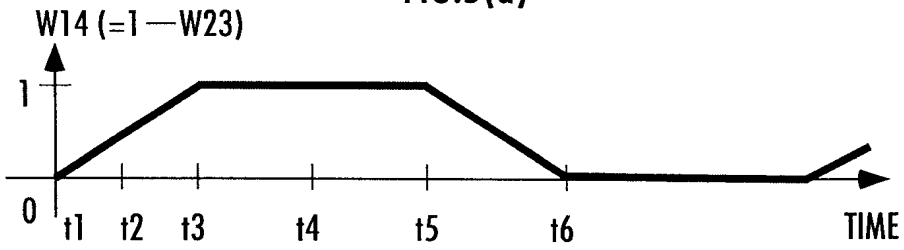


FIG.5(b)

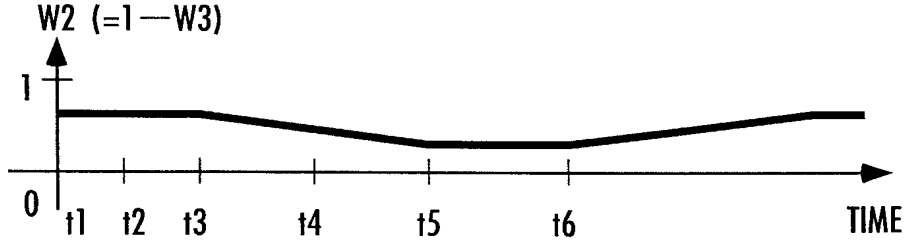


FIG.5(c)

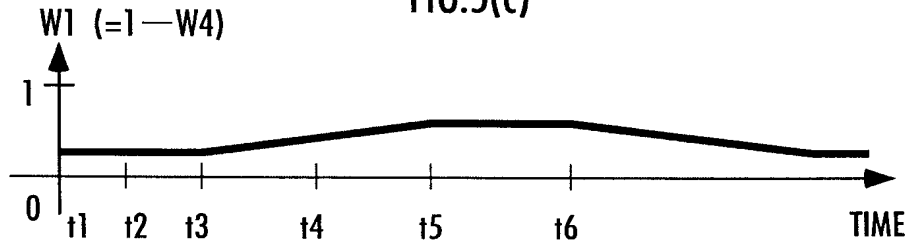


FIG.5(d)

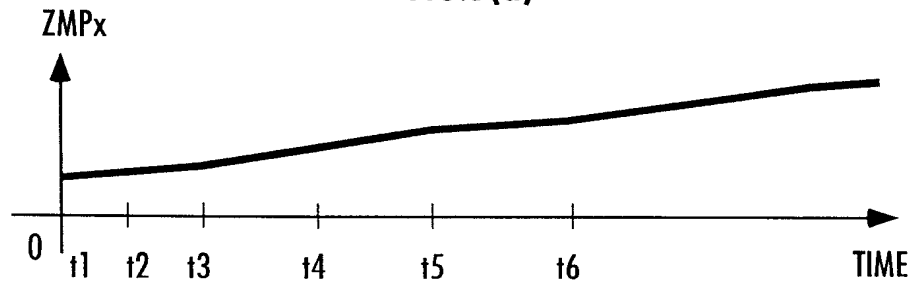


FIG.6

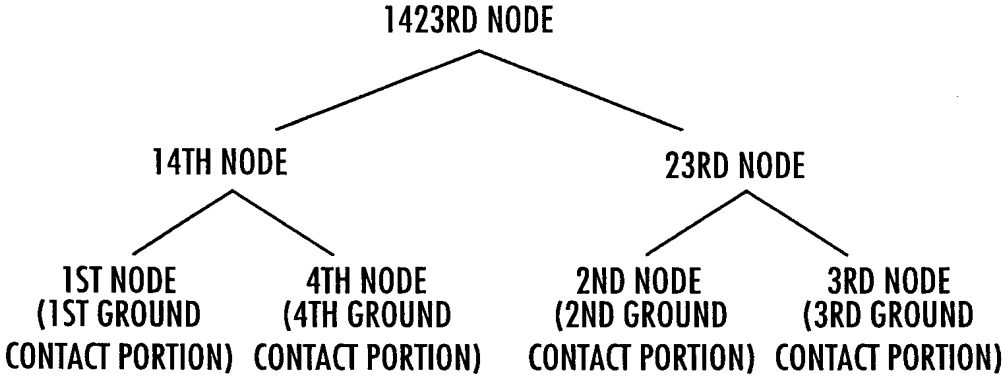
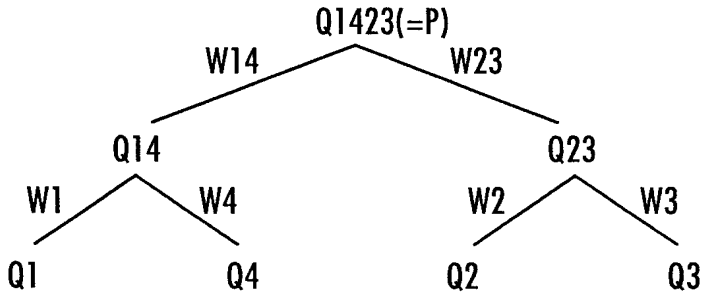
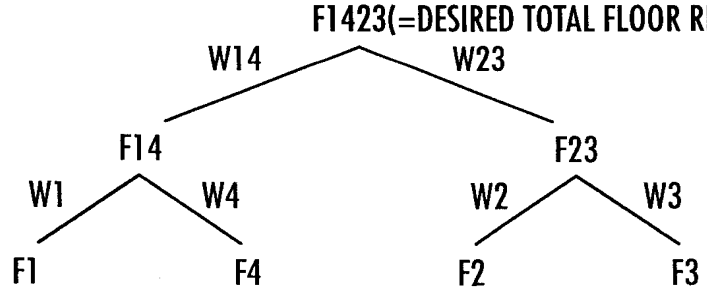


FIG.7



$$Q14 = W1 \cdot Q1 + W4 \cdot Q4$$
$$Q23 = W2 \cdot Q2 + W3 \cdot Q3$$
$$Q1423 = W14 \cdot Q14 + W23 \cdot Q23$$

FIG.8



$$F1 = W1 \cdot W14 \cdot Ftotalref$$
$$F4 = W4 \cdot W14 \cdot Ftotalref$$
$$F2 = W2 \cdot W23 \cdot Ftotalref$$
$$F3 = W3 \cdot W23 \cdot Ftotalref$$
$$F14 = F1 + F4$$
$$F23 = F2 + F3$$
$$F1423 = F14 + F23$$

FIG.9

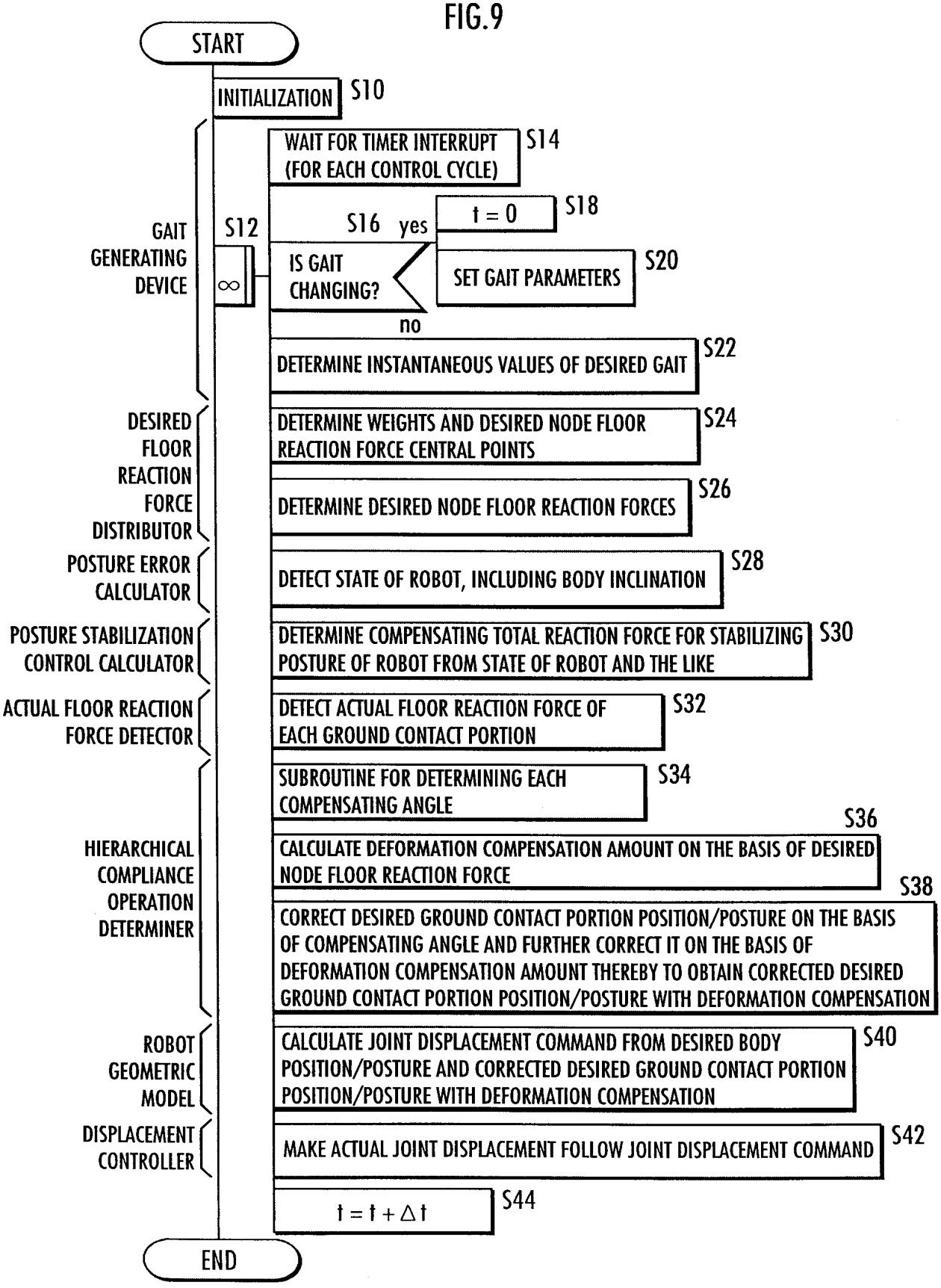

START
INITIALIZATION
S10
WAIT FOR TIMER INTERRUPT (FOR EACH CONTROL CYCLE)
S14
GAIT GENERATING DEVICE
S12
∞
S16
yes
t = 0
S18
IS GAIT CHANGING?
SET GAIT PARAMETERS
S20
no
DETERMINE INSTANTANEOUS VALUES OF DESIRED GAIT
S22
DESIRED FLOOR REACTION FORCE DISTRIBUTOR
DETERMINE WEIGHTS AND DESIRED NODE FLOOR REACTION FORCE CENTRAL POINTS
S24
DETERMINE DESIRED NODE FLOOR REACTION FORCES
S26
POSTURE ERROR CALCULATOR
DETECT STATE OF ROBOT, INCLUDING BODY INCLINATION
S28
POSTURE STABILIZATION CONTROL CALCULATOR
DETERMINE COMPENSATING TOTAL REACTION FORCE FOR STABILIZING POSTURE OF ROBOT FROM STATE OF ROBOT AND THE LIKE
S30
ACTUAL FLOOR REACTION FORCE DETECTOR
DETECT ACTUAL FLOOR REACTION FORCE OF EACH GROUND CONTACT PORTION
S32
SUBROUTINE FOR DETERMINING EACH COMPENSATING ANGLE
S34
S36
HIERARCHICAL COMPLIANCE OPERATION DETERMINER
CALCULATE DEFORMATION COMPENSATION AMOUNT ON THE BASIS OF DESIRED NODE FLOOR REACTION FORCE
S38
CORRECT DESIRED GROUND CONTACT PORTION POSITION/POSTURE ON THE BASIS OF COMPENSATING ANGLE AND FURTHER CORRECT IT ON THE BASIS OF DEFORMATION COMPENSATION AMOUNT THEREBY TO OBTAIN CORRECTED DESIRED GROUND CONTACT PORTION POSITION/POSTURE WITH DEFORMATION COMPENSATION
ROBOT GEOMETRIC MODEL
CALCULATE JOINT DISPLACEMENT COMMAND FROM DESIRED BODY POSITION/POSTURE AND CORRECTED DESIRED GROUND CONTACT PORTION POSITION/POSTURE WITH DEFORMATION COMPENSATION
S40
DISPLACEMENT CONTROLLER
MAKE ACTUAL JOINT DISPLACEMENT FOLLOW JOINT DISPLACEMENT COMMAND
S42
t = t + Δt
S44
END

FIG.10

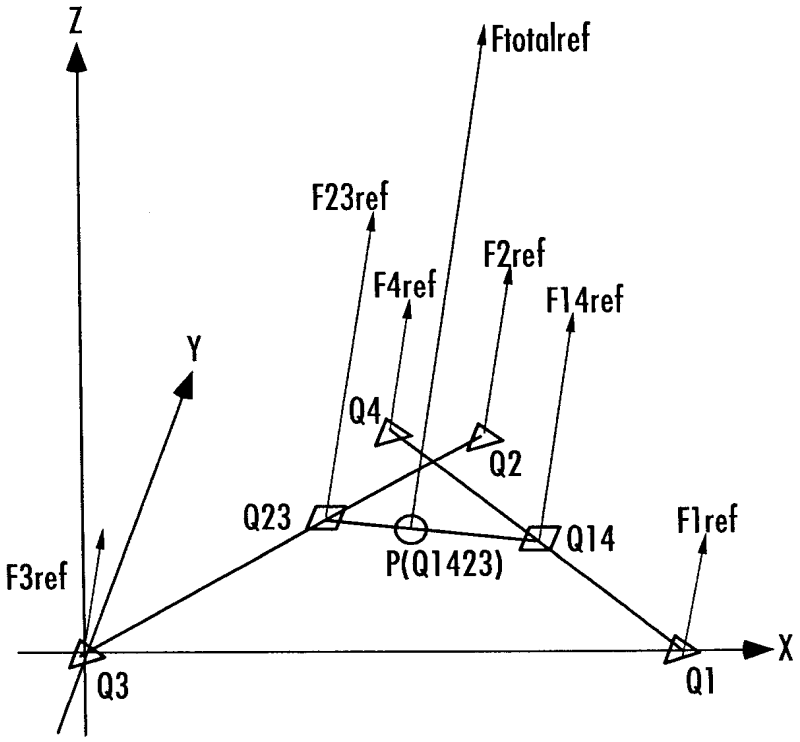

Z
Ftotalref
F23ref
F2ref
F4ref
F14ref
Y
Q4
Q2
Q23
Q14
F1ref
P(Q1423)
F3ref
X
Q3
Q1

FIG.11

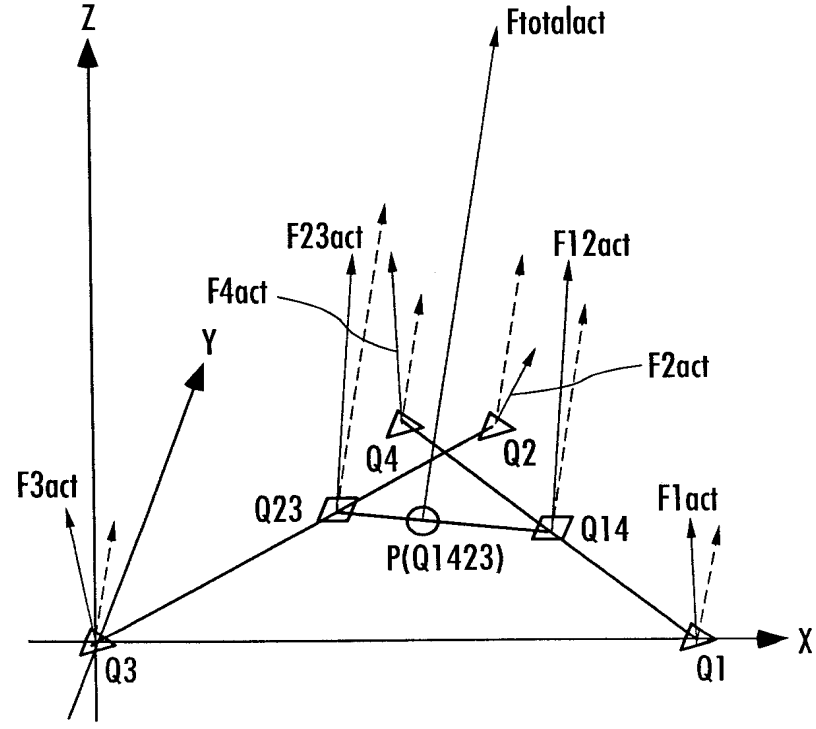

Z
Ftotalact
F23act
F12act
F4act
Y
F2act
Q4
Q2
F3act
Q23
F1act
Q14
P(Q1423)
X
Q3
Q1

FIG.12

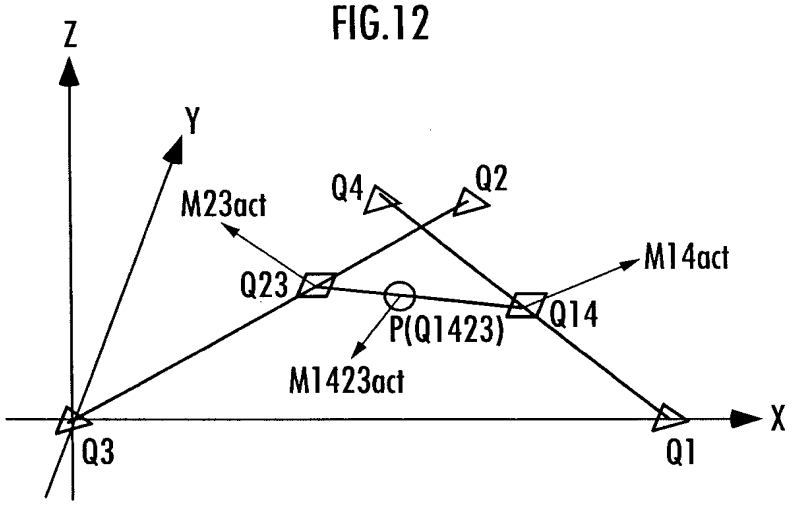


FIG.13

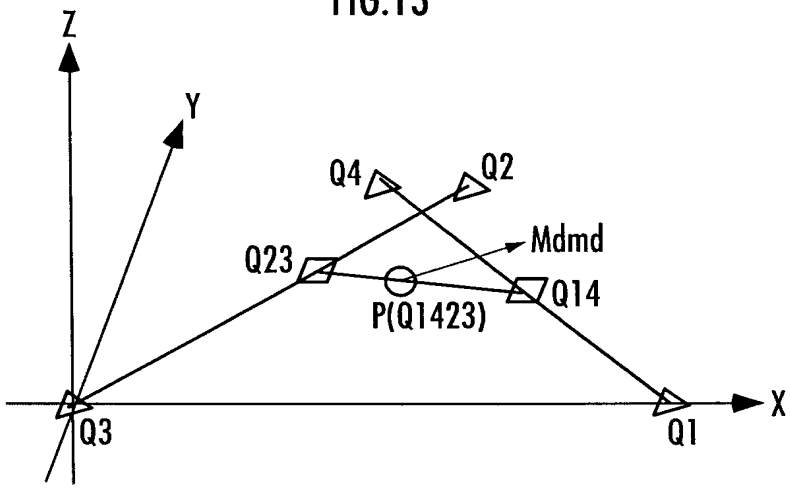


FIG.14

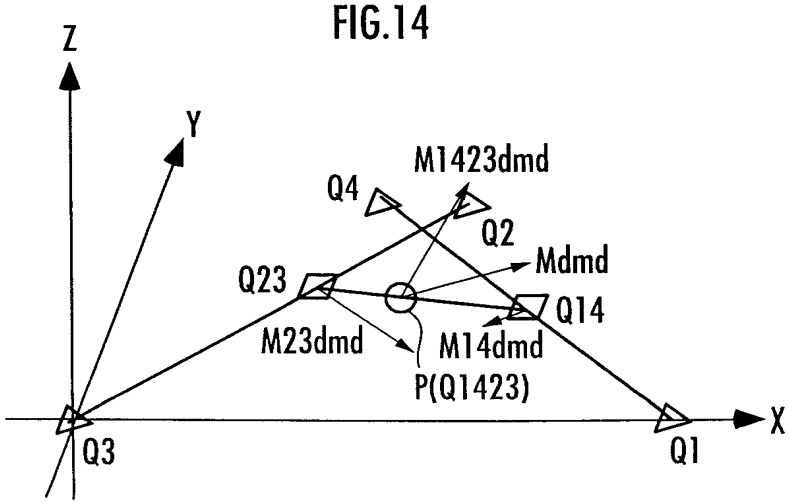


FIG.15

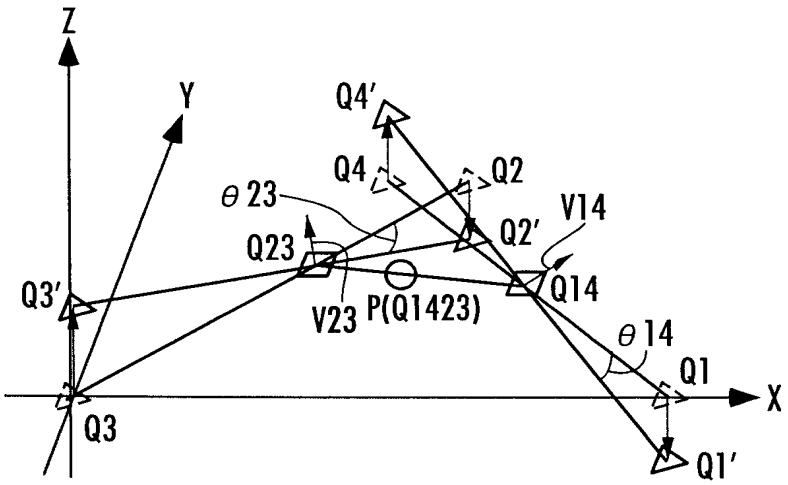

Z
Y
Q4'
Q4
Q2
θ23
V14
Q23
Q2'
Q3'
Q14
V23
P(Q1423)
θ14
Q1
X
Q3
Q1'

FIG.16

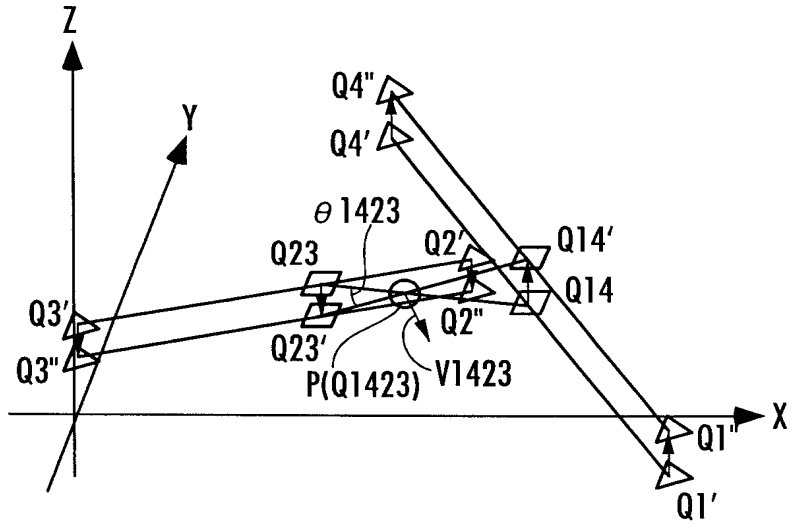

Z
Y
Q4"
Q4'
θ1423
Q23
Q2'
Q14'
Q14
Q3'
Q2"
Q23'
Q3"
P(Q1423)
V1423
X
Q1"
Q1'

FIG.17

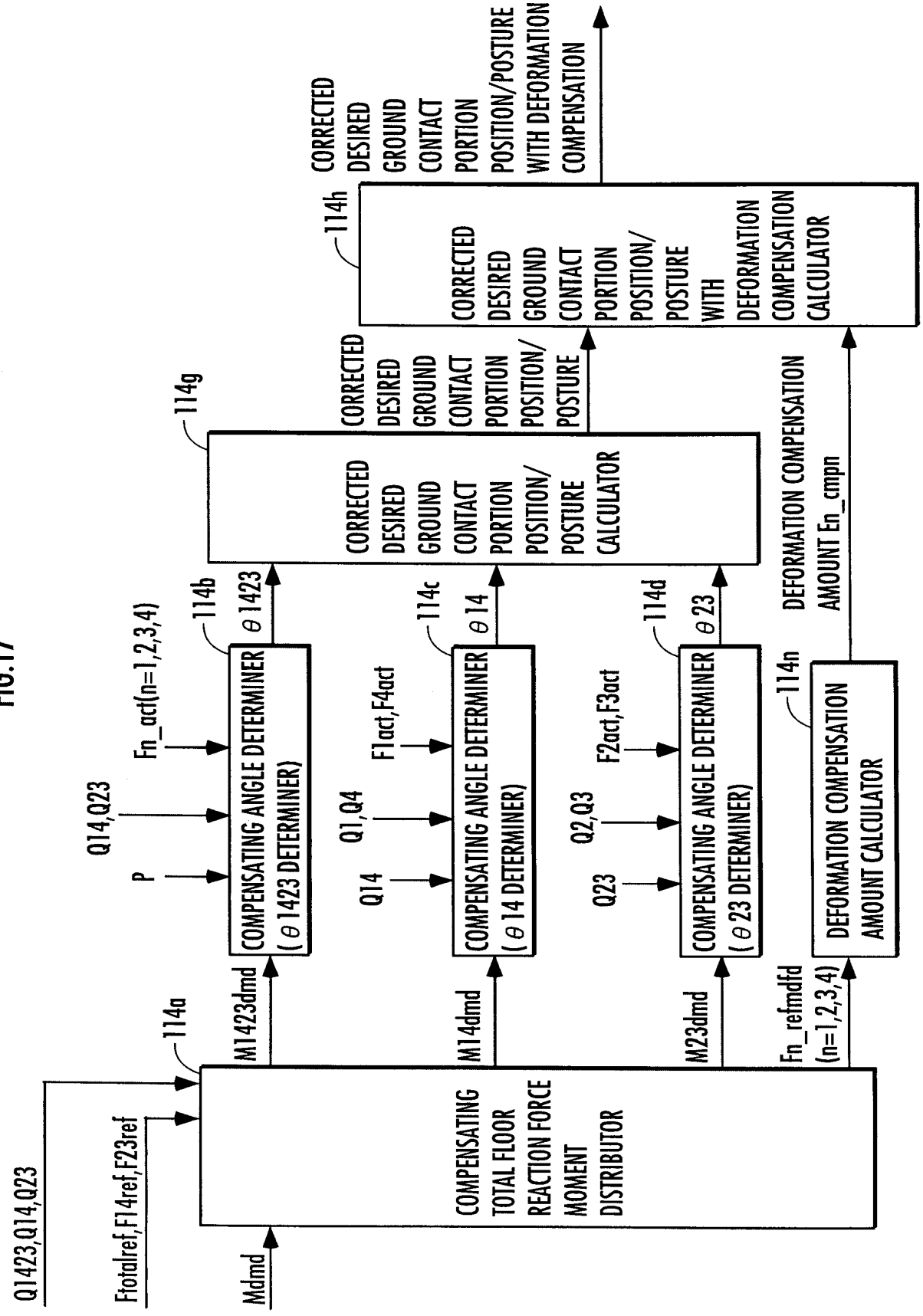

Q1423,Q14,Q23
Ftotalref,F14ref,F23ref
Mdmd
COMPENSATING TOTAL FLOOR REACTION FORCE MOMENT DISTRIBUTOR
114a
M1423dmd
M14dmd
M23dmd
Fn_refmdfd (n=1,2,3,4)
Q14,Q23
P
Fn_act(n=1,2,3,4)
COMPENSATING ANGLE DETERMINER (θ1423 DETERMINER)
114b
θ1423
Q1,Q4
Q14
F1act,F4act
COMPENSATING ANGLE DETERMINER (θ14 DETERMINER)
114c
θ14
Q2,Q3
Q23
F2act,F3act
COMPENSATING ANGLE DETERMINER (θ23 DETERMINER)
114d
θ23
DEFORMATION COMPENSATION AMOUNT CALCULATOR
114n
DEFORMATION COMPENSATION AMOUNT En_cmpn
CORRECTED DESIRED GROUND CONTACT PORTION POSITION/ POSTURE CALCULATOR
114g
CORRECTED DESIRED GROUND CONTACT PORTION POSITION/ POSTURE
CORRECTED DESIRED GROUND CONTACT PORTION POSITION/ POSTURE WITH DEFORMATION COMPENSATION CALCULATOR
114h
CORRECTED DESIRED GROUND CONTACT PORTION POSITION/POSTURE WITH DEFORMATION COMPENSATION

FIG.18

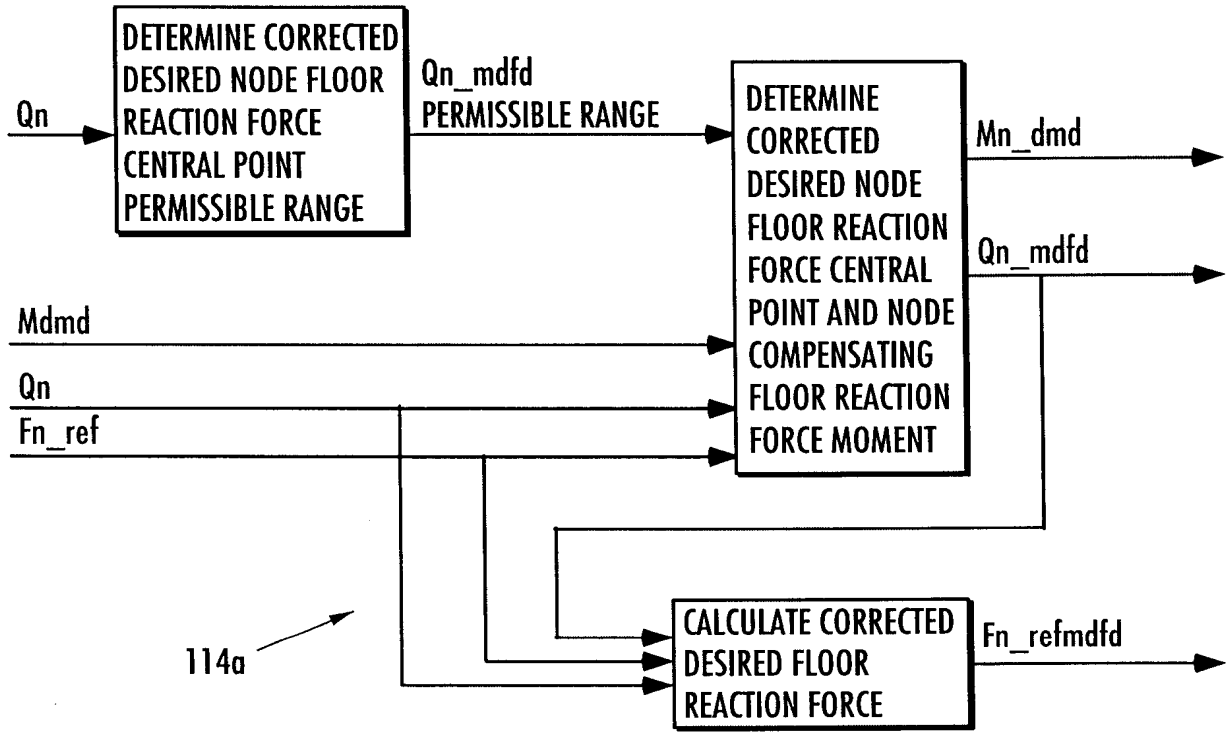

Qn
DETERMINE CORRECTED DESIRED NODE FLOOR REACTION FORCE CENTRAL POINT PERMISSIBLE RANGE
Qn_mdfd
PERMISSIBLE RANGE
DETERMINE CORRECTED DESIRED NODE FLOOR REACTION FORCE CENTRAL POINT AND NODE COMPENSATING FLOOR REACTION FORCE MOMENT
Mn_dmd
Qn_mdfd
Mdmd
Qn
Fn_ref
114a
CALCULATE CORRECTED DESIRED FLOOR REACTION FORCE
Fn_refmdfd

FIG.19

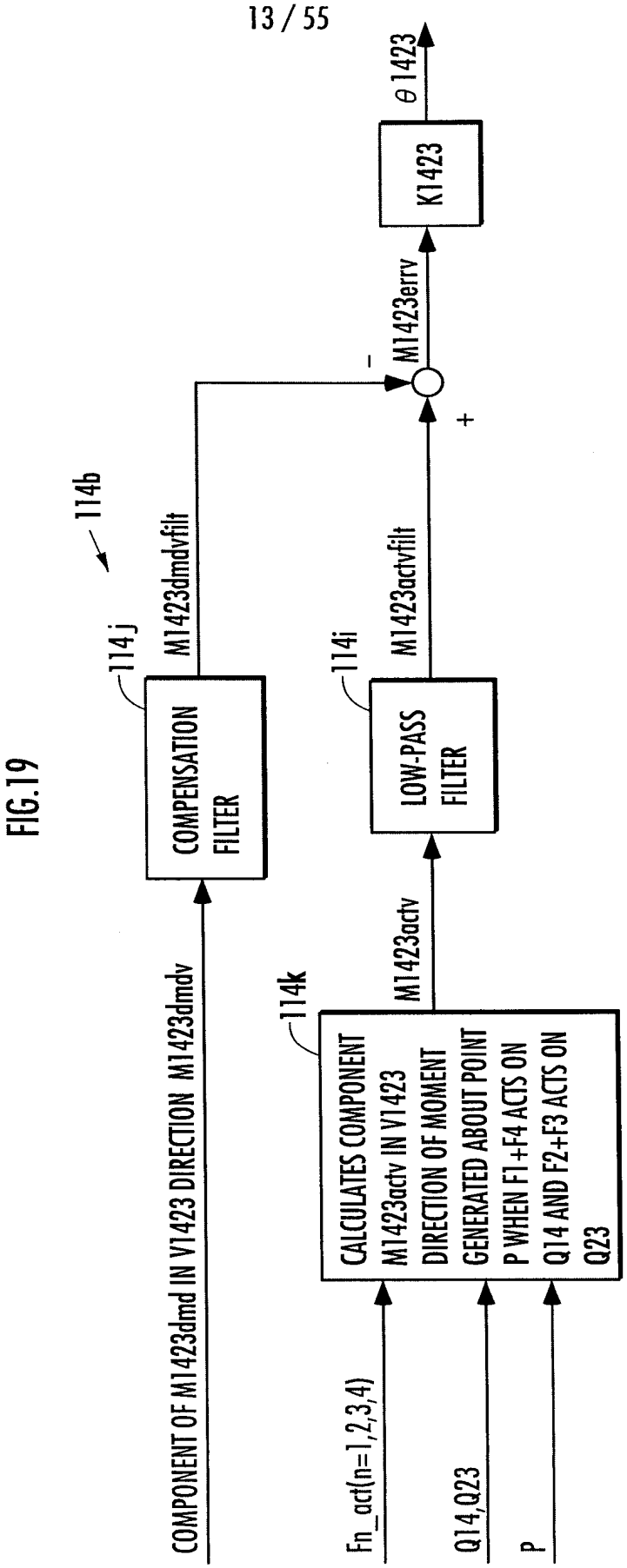

114b
114j
M1423dmdvfilt
COMPENSATION FILTER
114i
M1423actvfilt
LOW-PASS FILTER
M1423errv
K1423
θ1423
−
+
114k
M1423actv
CALCULATES COMPONENT M1423actv IN V1423 DIRECTION OF MOMENT GENERATED ABOUT POINT P WHEN F1+F4 ACTS ON Q14 AND F2+F3 ACTS ON Q23
COMPONENT OF M1423dmd IN V1423 DIRECTION M1423dmdv
Fn_act(n=1,2,3,4)
Q14,Q23
P

FIG.20

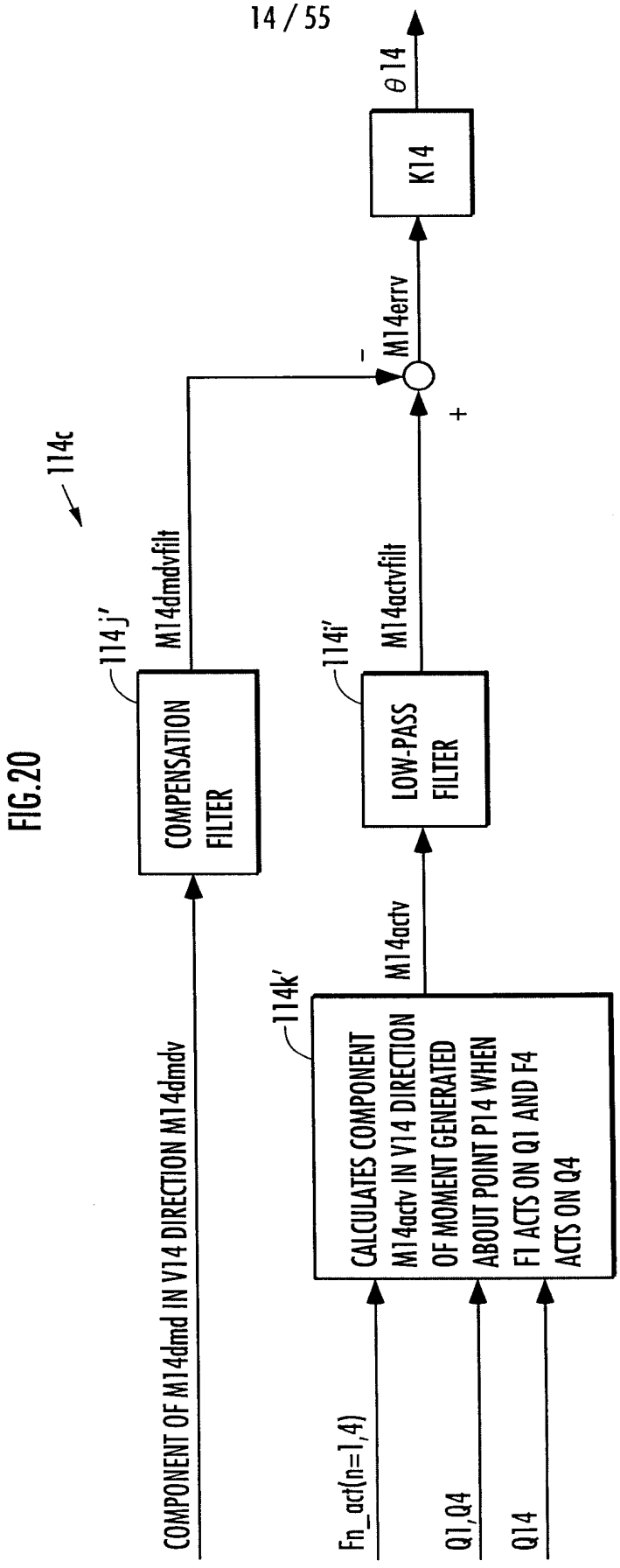

θ14
K14
M14errv
-
+
114c
114j'
M14dmdvfilt
COMPENSATION FILTER
114i'
M14actvfilt
LOW-PASS FILTER
M14actv
114k'
CALCULATES COMPONENT M14actv IN V14 DIRECTION OF MOMENT GENERATED ABOUT POINT P14 WHEN F1 ACTS ON Q1 AND F4 ACTS ON Q4
COMPONENT OF M14dmd IN V14 DIRECTION M14dmdv
Fn_act(n=1,4)
Q1,Q4
Q14

FIG.21

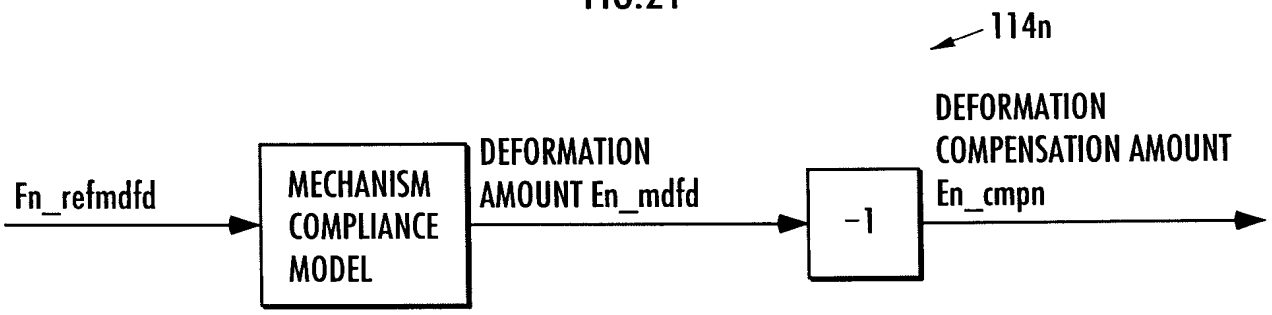

114n
Fn_refmdfd
MECHANISM COMPLIANCE MODEL
DEFORMATION AMOUNT En_mdfd
-1
DEFORMATION COMPENSATION AMOUNT En_cmpn

FIG.22

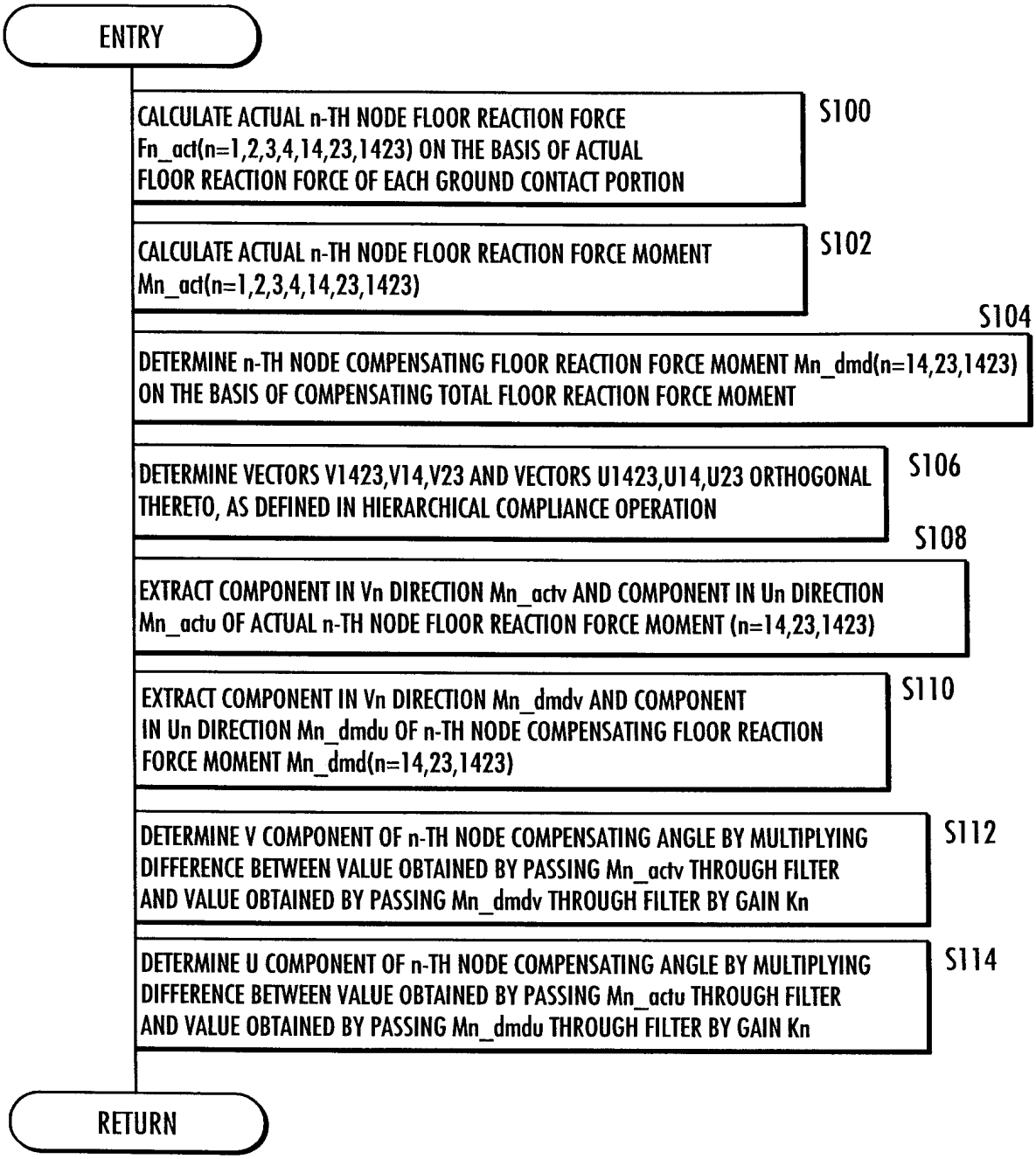

ENTRY
CALCULATE ACTUAL n-TH NODE FLOOR REACTION FORCE Fn_act(n=1,2,3,4,14,23,1423) ON THE BASIS OF ACTUAL FLOOR REACTION FORCE OF EACH GROUND CONTACT PORTION
S100
CALCULATE ACTUAL n-TH NODE FLOOR REACTION FORCE MOMENT Mn_act(n=1,2,3,4,14,23,1423)
S102
S104
DETERMINE n-TH NODE COMPENSATING FLOOR REACTION FORCE MOMENT Mn_dmd(n=14,23,1423) ON THE BASIS OF COMPENSATING TOTAL FLOOR REACTION FORCE MOMENT
DETERMINE VECTORS V1423,V14,V23 AND VECTORS U1423,U14,U23 ORTHOGONAL THERETO, AS DEFINED IN HIERARCHICAL COMPLIANCE OPERATION
S106
S108
EXTRACT COMPONENT IN Vn DIRECTION Mn_actv AND COMPONENT IN Un DIRECTION Mn_actu OF ACTUAL n-TH NODE FLOOR REACTION FORCE MOMENT (n=14,23,1423)
EXTRACT COMPONENT IN Vn DIRECTION Mn_dmdv AND COMPONENT IN Un DIRECTION Mn_dmdu OF n-TH NODE COMPENSATING FLOOR REACTION FORCE MOMENT Mn_dmd(n=14,23,1423)
S110
DETERMINE V COMPONENT OF n-TH NODE COMPENSATING ANGLE BY MULTIPLYING DIFFERENCE BETWEEN VALUE OBTAINED BY PASSING Mn_actv THROUGH FILTER AND VALUE OBTAINED BY PASSING Mn_dmdv THROUGH FILTER BY GAIN Kn
S112
DETERMINE U COMPONENT OF n-TH NODE COMPENSATING ANGLE BY MULTIPLYING DIFFERENCE BETWEEN VALUE OBTAINED BY PASSING Mn_actu THROUGH FILTER AND VALUE OBTAINED BY PASSING Mn_dmdu THROUGH FILTER BY GAIN Kn
S114
RETURN

FIG.23

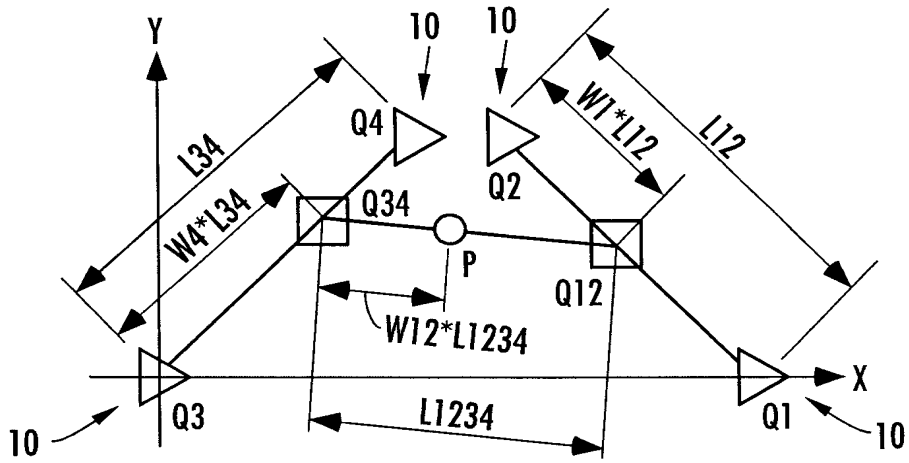

Y
10
10
Q4
Q2
W1*L12
L12
L34
W4*L34
Q34
P
Q12
W12*L1234
X
Q3
L1234
Q1
10
10

FIG.24

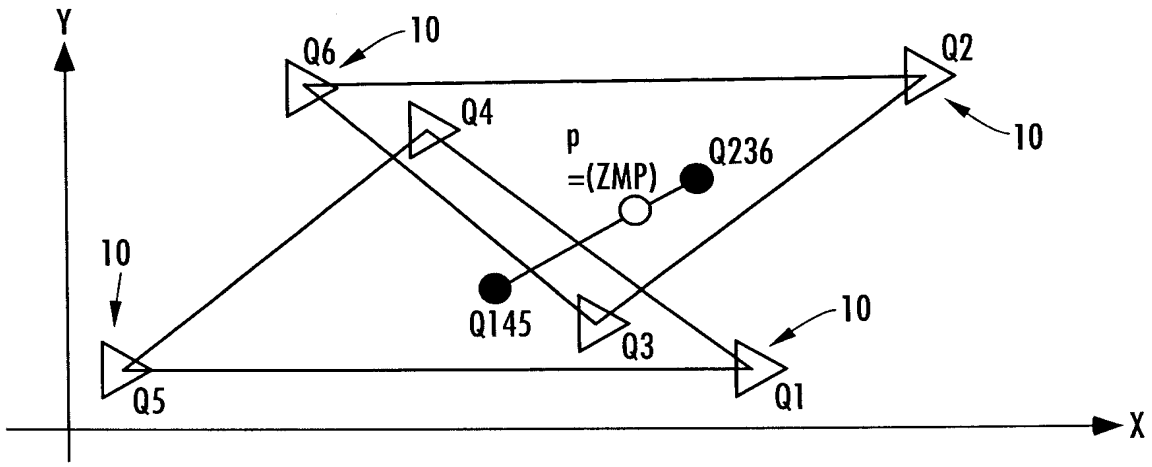


FIG.25

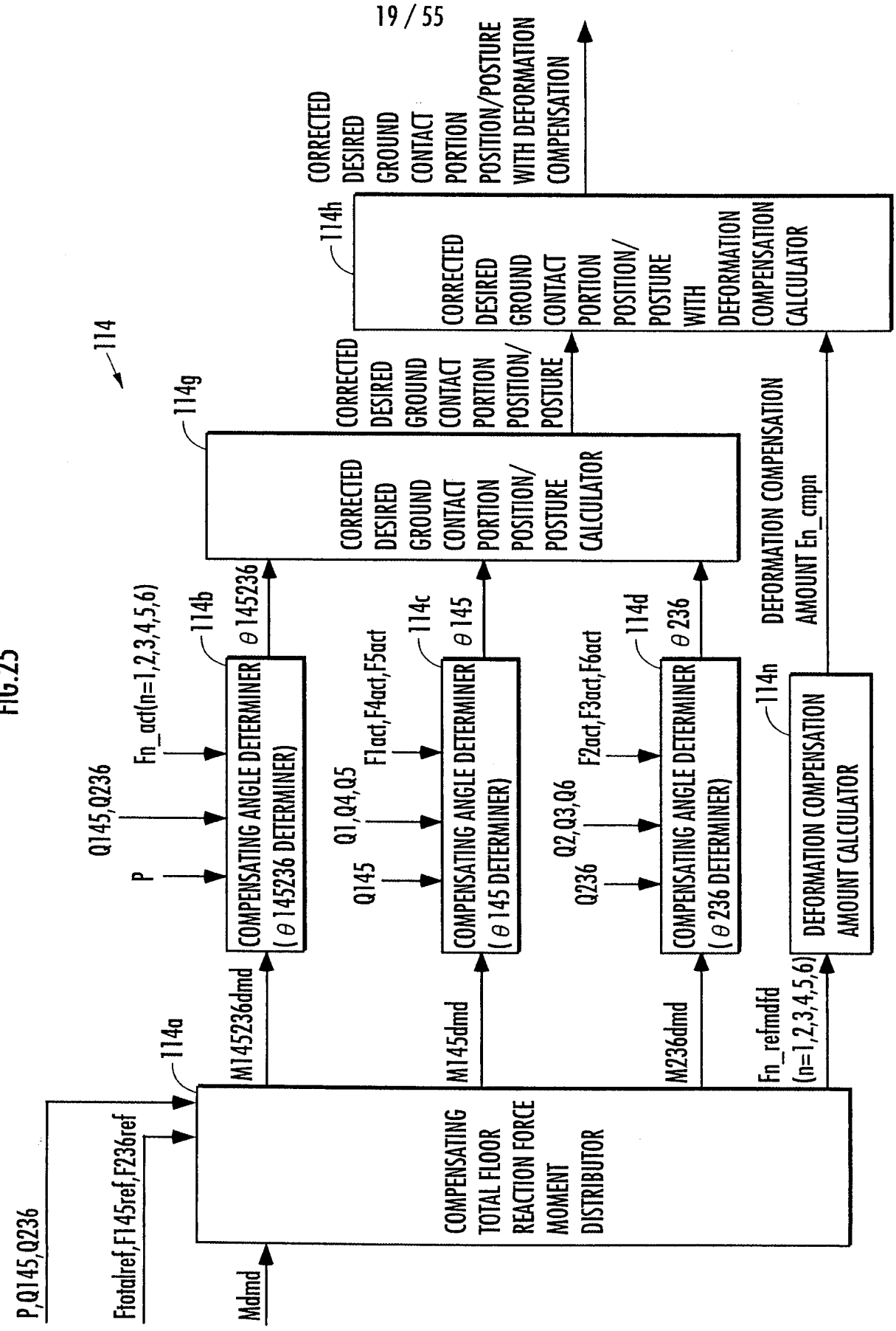

P,Q145,Q236
Ftotalref,F145ref,F236ref
Mdmd
114a
COMPENSATING TOTAL FLOOR REACTION FORCE MOMENT DISTRIBUTOR
M145236dmd
M145dmd
M236dmd
Fn_refmdfd (n=1,2,3,4,5,6)
114
114g
114h
114n
CORRECTED DESIRED GROUND CONTACT PORTION POSITION/POSTURE CALCULATOR
CORRECTED DESIRED GROUND CONTACT PORTION POSITION/ POSTURE WITH DEFORMATION COMPENSATION CALCULATOR
DEFORMATION COMPENSATION AMOUNT CALCULATOR
DEFORMATION COMPENSATION AMOUNT En_cmpn
CORRECTED DESIRED GROUND CONTACT PORTION POSITION/POSTURE WITH DEFORMATION COMPENSATION
P
Q145,Q236
Fn_act(n=1,2,3,4,5,6)
114b
θ145236
COMPENSATING ANGLE DETERMINER (θ145236 DETERMINER)
Q145
Q1,Q4,Q5
F1act,F4act,F5act
114c
θ145
COMPENSATING ANGLE DETERMINER (θ145 DETERMINER)
Q236
Q2,Q3,Q6
F2act,F3act,F6act
114d
θ236
COMPENSATING ANGLE DETERMINER (θ236 DETERMINER)

FIG.26

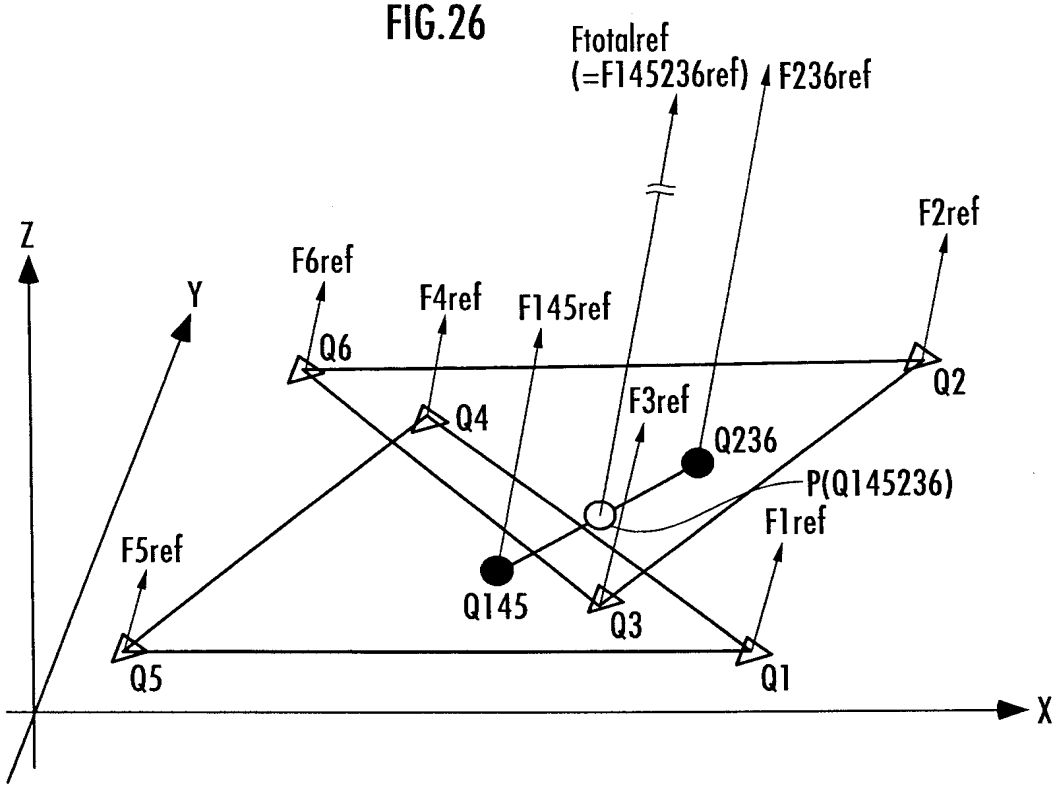

Ftotalref
(=F145236ref)
F236ref
F2ref
F6ref
F4ref
F145ref
Z
Y
Q6
Q2
Q4
F3ref
Q236
P(Q145236)
F1ref
F5ref
Q145
Q3
Q5
Q1
X

FIG.27

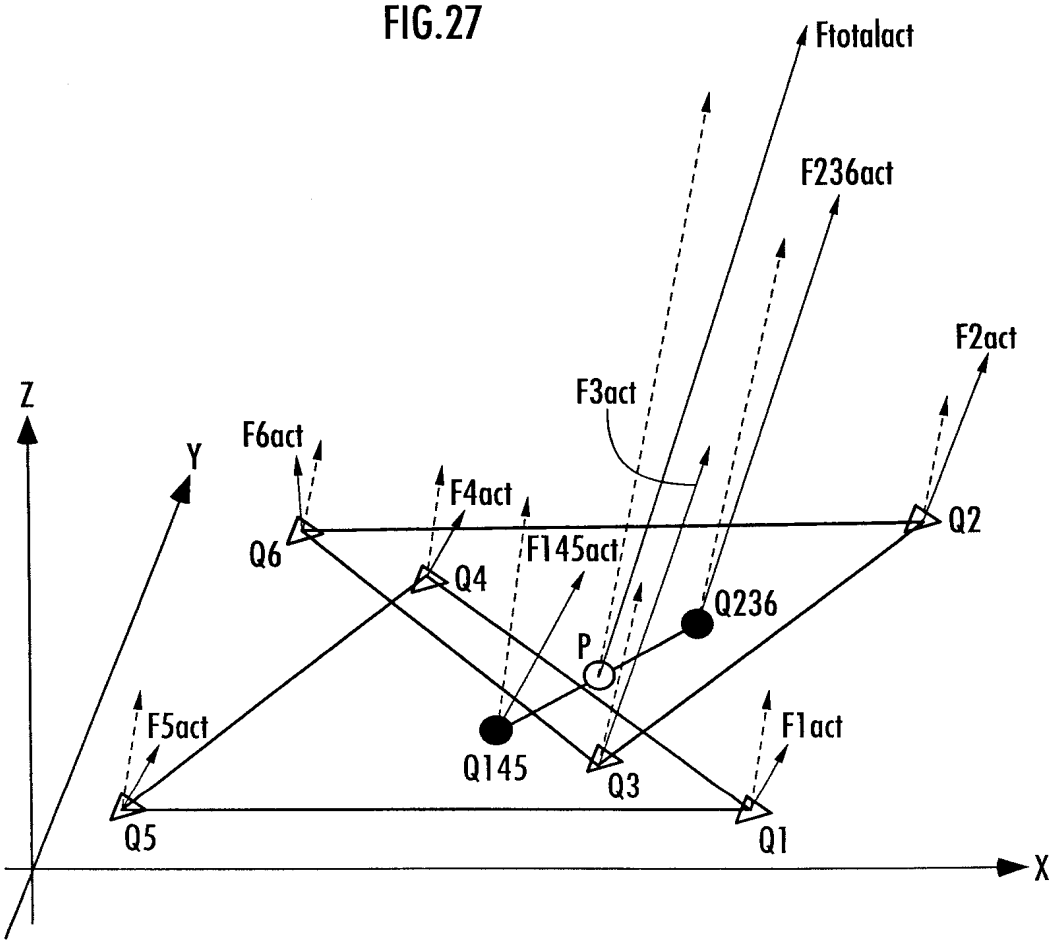

Ftotalact
F236act
F2act
F3act
Z
F6act
Y
F4act
Q2
Q6
F145act
Q4
Q236
P
F5act
F1act
Q145
Q3
Q5
Q1
X

FIG.28

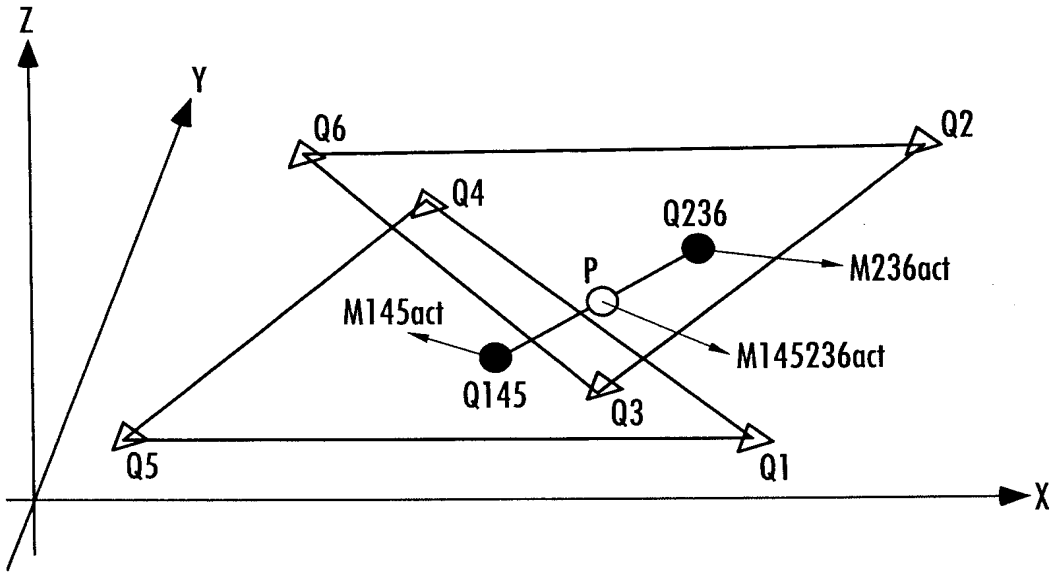


FIG.29(a)

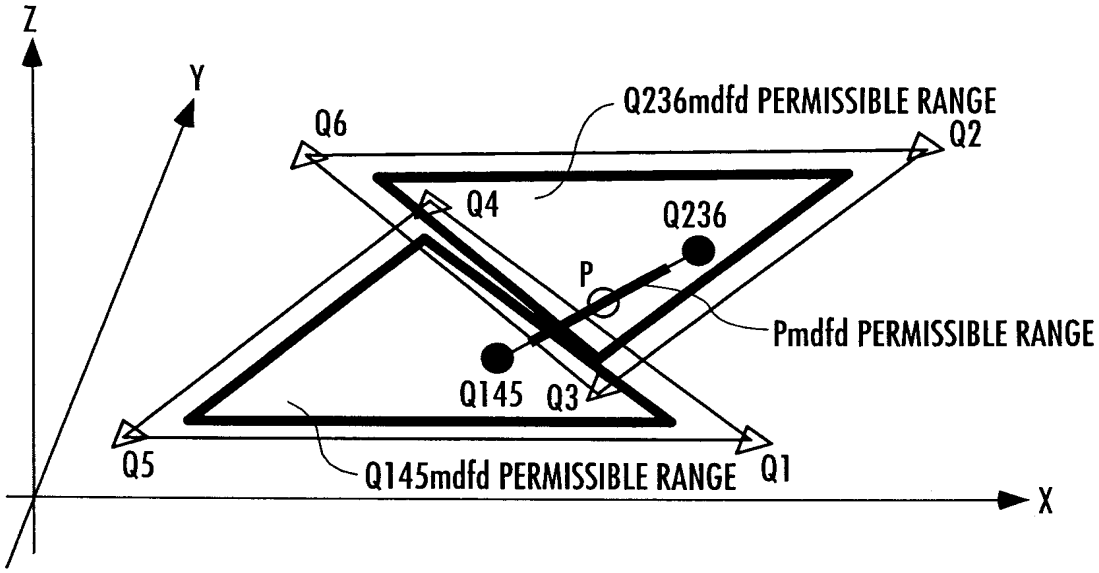


FIG.29(b)

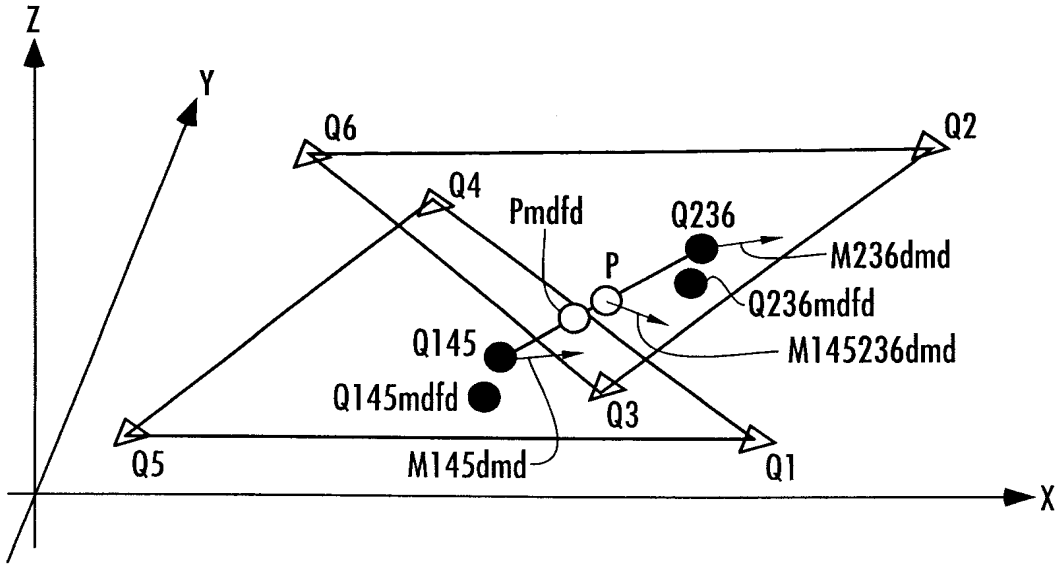


FIG.30

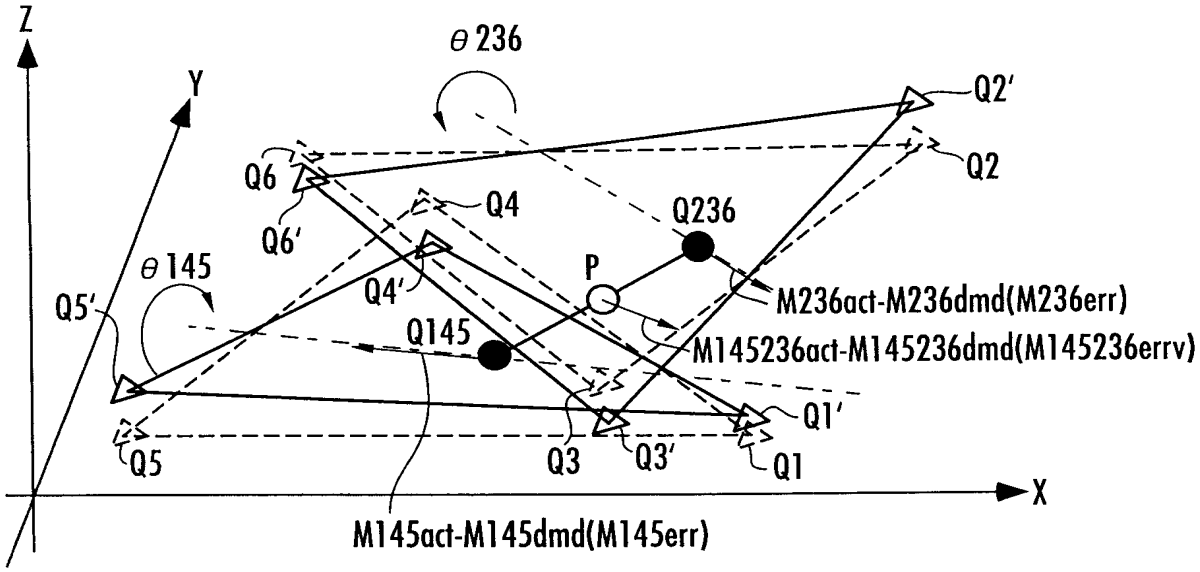

Z
Y
θ236
Q2'
Q2
Q6
Q6'
Q4
Q4'
Q236
P
θ145
Q5'
Q145
M236act-M236dmd(M236err)
M145236act-M145236dmd(M145236errv)
Q1'
Q5
Q3
Q3'
Q1
X
M145act-M145dmd(M145err)

FIG.31

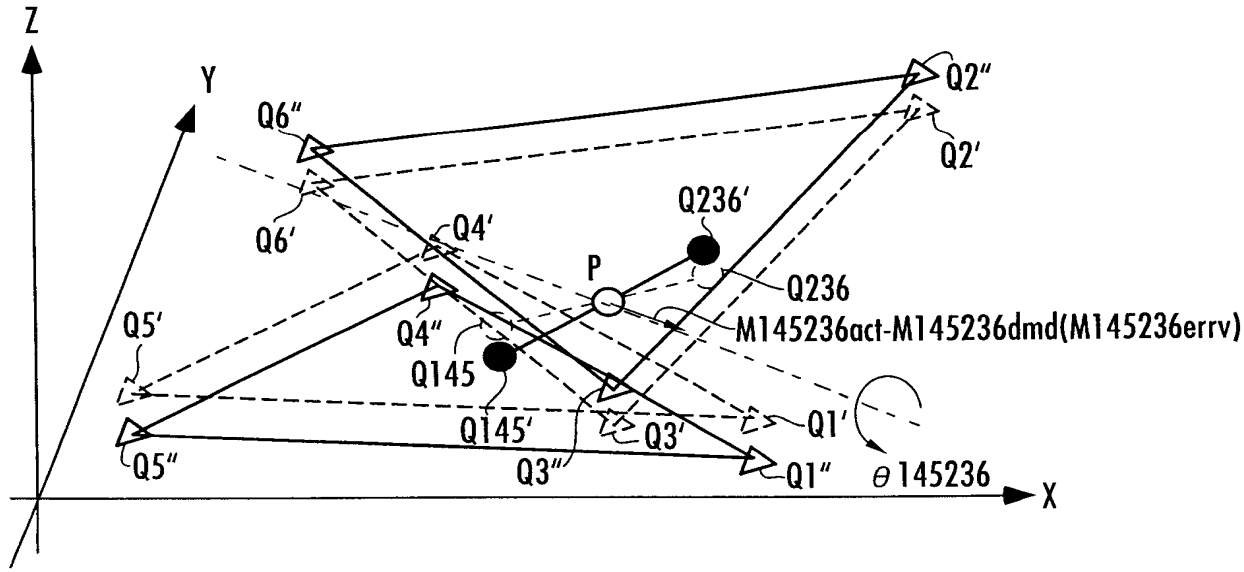

Z
Y
Q2"
Q6"
Q2'
Q6'
Q4'
Q236'
P
Q236
Q5'
Q4"
M145236act-M145236dmd(M145236errv)
Q145
Q145'
Q3'
Q1'
Q5"
Q3"
Q1"
θ145236
X

FIG.32

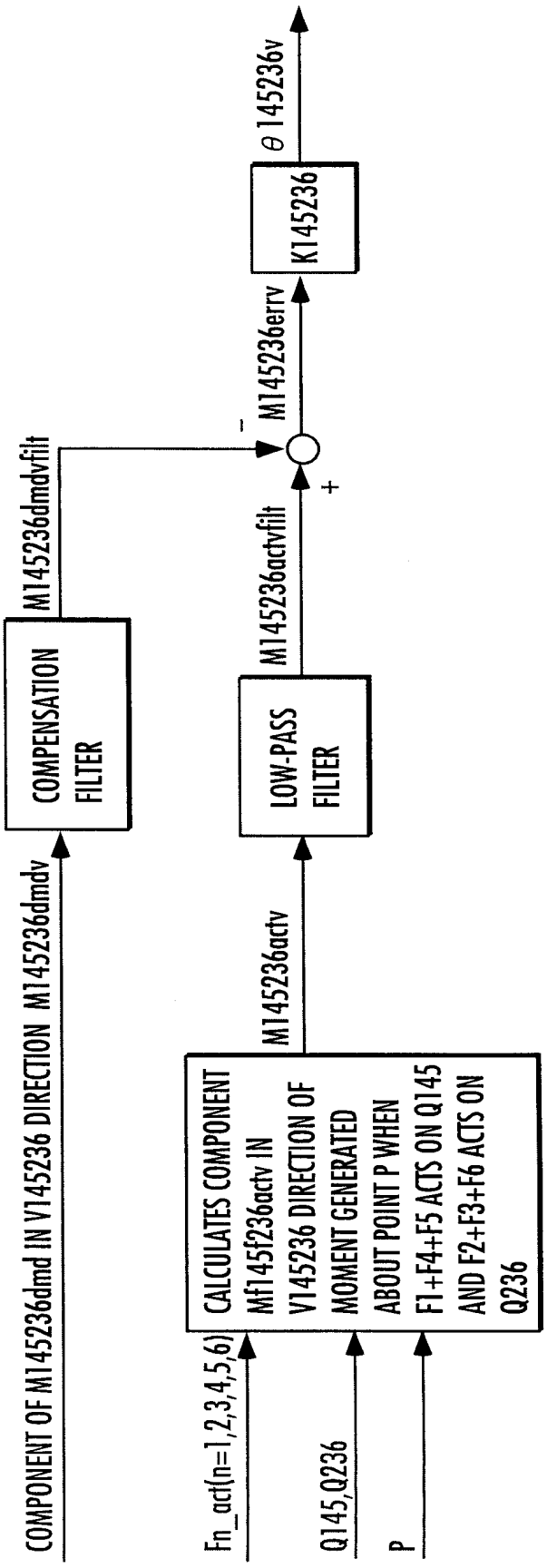

θ145236v
K145236
M145236errv
−
+
M145236dmdvfilt
M145236actvfilt
COMPENSATION FILTER
LOW-PASS FILTER
M145236actv
COMPONENT OF M145236dmd IN V145236 DIRECTION M145236dmdv
CALCULATES COMPONENT Mf145f236actv IN V145236 DIRECTION OF MOMENT GENERATED ABOUT POINT P WHEN F1+F4+F5 ACTS ON Q145 AND F2+F3+F6 ACTS ON Q236
Fn_act(n=1,2,3,4,5,6)
Q145,Q236
P

FIG.33

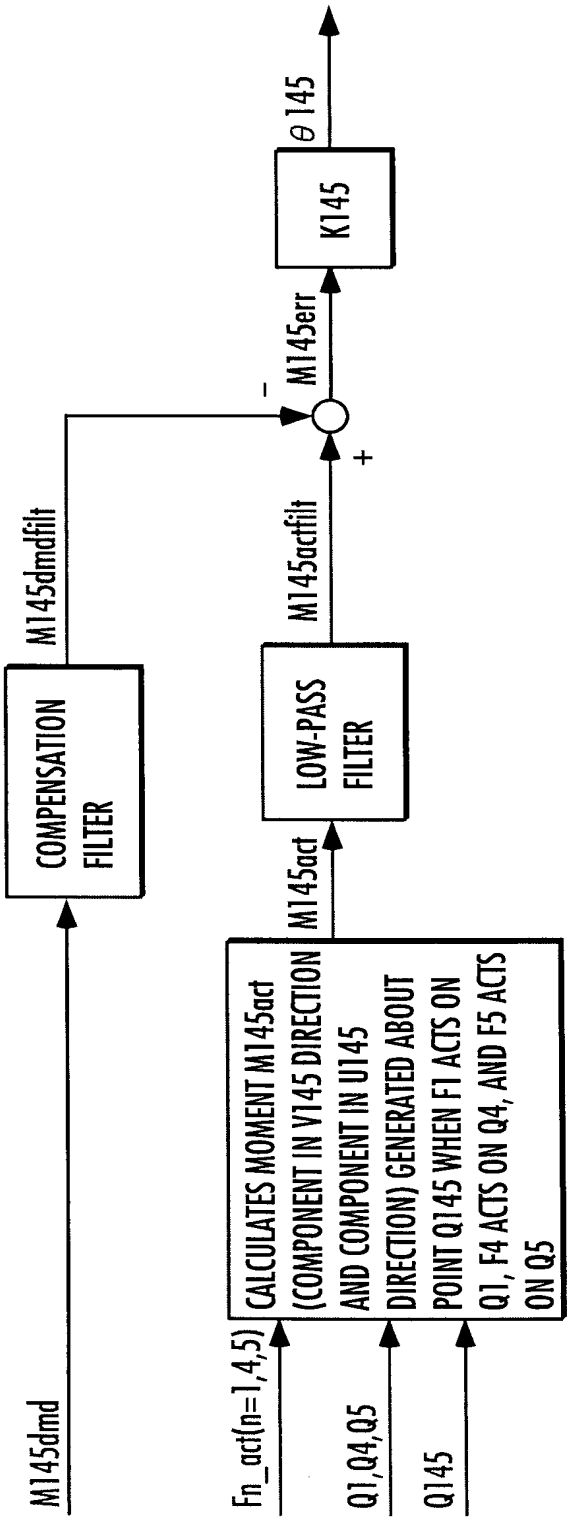

M145dmd
COMPENSATION FILTER
M145dmdfilt
LOW-PASS FILTER
M145actfilt
M145act
CALCULATES MOMENT M145act (COMPONENT IN V145 DIRECTION AND COMPONENT IN U145 DIRECTION) GENERATED ABOUT POINT Q145 WHEN F1 ACTS ON Q1, F4 ACTS ON Q4, AND F5 ACTS ON Q5
Fn_act(n=1,4,5)
Q1,Q4,Q5
Q145
M145err
K145
θ145
+
-

FIG.34

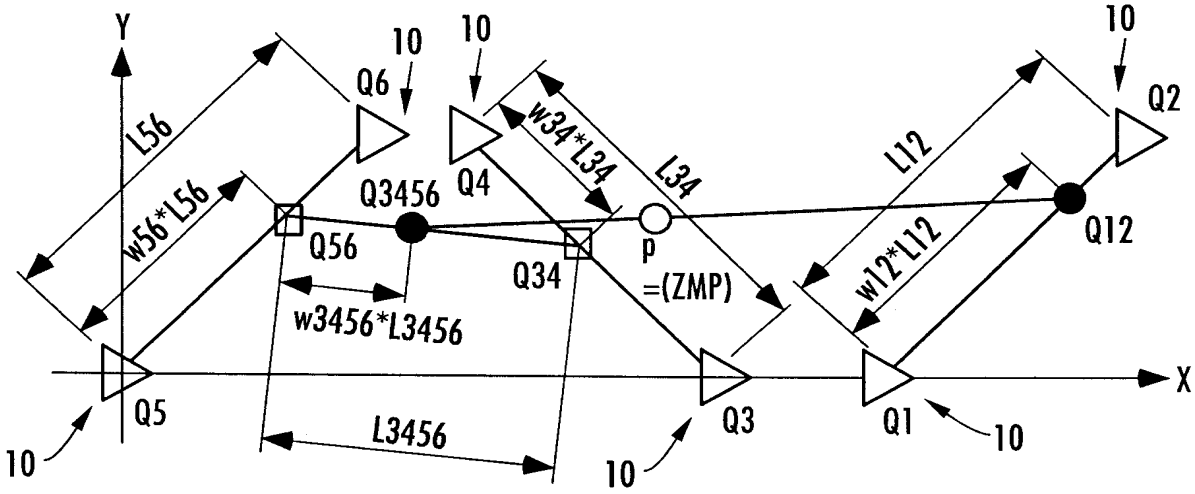

Y
10
10
10
Q6
Q4
Q2
L56
w34*L34
L34
L12
w56*L56
Q3456
Q56
Q34
p
=(ZMP)
Q12
w12*L12
w3456*L3456
X
Q5
L3456
Q3
Q1
10
10
10

FIG.35

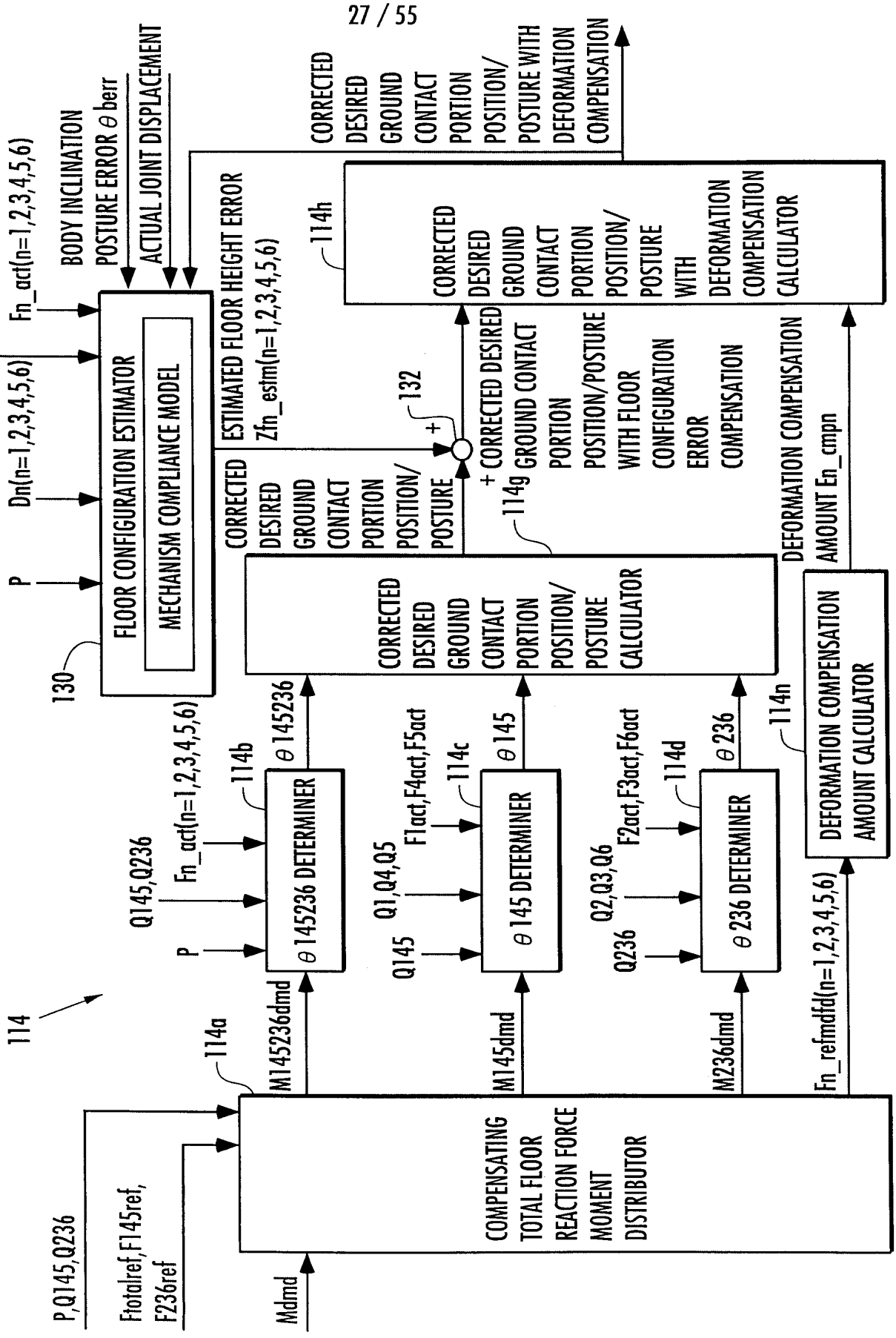

P,Q145,Q236
Ftotalref,F145ref,
F236ref
Mdmd
114
114a
COMPENSATING TOTAL FLOOR REACTION FORCE MOMENT DISTRIBUTOR
M145236dmd
M145dmd
M236dmd
Fn_refmdfd(n=1,2,3,4,5,6)
114b
114c
114d
114n
θ145236 DETERMINER
θ145 DETERMINER
θ236 DETERMINER
DEFORMATION COMPENSATION AMOUNT CALCULATOR
DEFORMATION COMPENSATION AMOUNT En_cmpn
Q145,Q236
Fn_act(n=1,2,3,4,5,6)
Q1,Q4,Q5
F1act,F4act,F5act
Q145
Q2,Q3,Q6
F2act,F3act,F6act
Q236
P
θ145236
θ145
θ236
CORRECTED DESIRED GROUND CONTACT PORTION POSITION/POSTURE CALCULATOR
114g
+ CORRECTED DESIRED GROUND CONTACT PORTION POSITION/POSTURE WITH FLOOR CONFIGURATION ERROR COMPENSATION
132
CORRECTED DESIRED GROUND CONTACT PORTION POSITION/POSTURE
ESTIMATED FLOOR HEIGHT ERROR Zfn_estm(n=1,2,3,4,5,6)
114h
CORRECTED DESIRED GROUND CONTACT PORTION POSITION/POSTURE WITH DEFORMATION COMPENSATION CALCULATOR
CORRECTED DESIRED GROUND CONTACT PORTION POSITION/POSTURE WITH DEFORMATION COMPENSATION
130
FLOOR CONFIGURATION ESTIMATOR
MECHANISM COMPLIANCE MODEL
Qn(n=1,2,3,4,5,6)
Dn(n=1,2,3,4,5,6)
Fn_act(n=1,2,3,4,5,6)
BODY INCLINATION POSTURE ERROR θberr
ACTUAL JOINT DISPLACEMENT

FIG.36

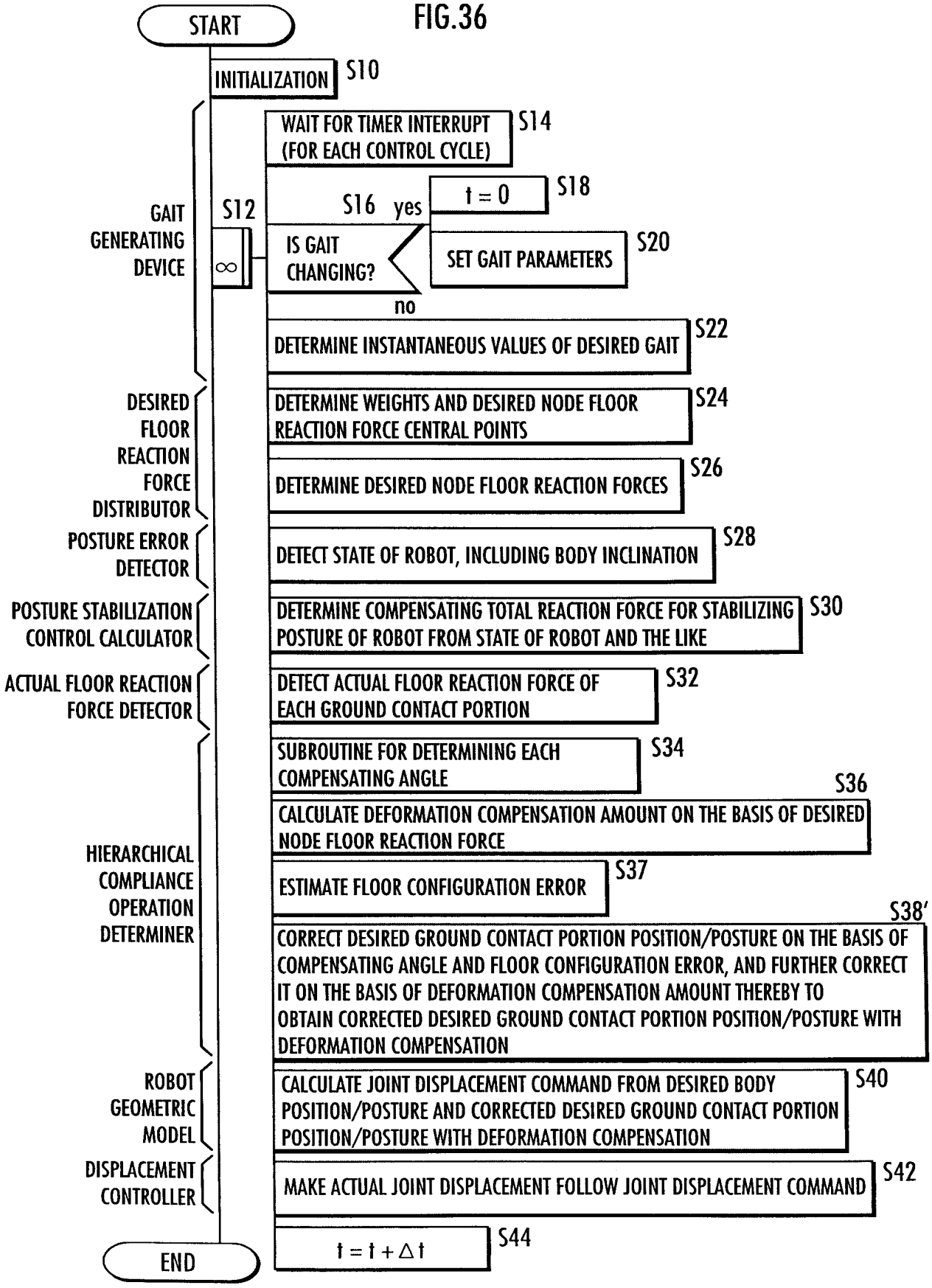

START
INITIALIZATION
S10
WAIT FOR TIMER INTERRUPT (FOR EACH CONTROL CYCLE)
S14
GAIT GENERATING DEVICE
S12
∞
S16
IS GAIT CHANGING?
yes
t = 0
S18
SET GAIT PARAMETERS
S20
no
DETERMINE INSTANTANEOUS VALUES OF DESIRED GAIT
S22
DESIRED FLOOR REACTION FORCE DISTRIBUTOR
DETERMINE WEIGHTS AND DESIRED NODE FLOOR REACTION FORCE CENTRAL POINTS
S24
DETERMINE DESIRED NODE FLOOR REACTION FORCES
S26
POSTURE ERROR DETECTOR
DETECT STATE OF ROBOT, INCLUDING BODY INCLINATION
S28
POSTURE STABILIZATION CONTROL CALCULATOR
DETERMINE COMPENSATING TOTAL REACTION FORCE FOR STABILIZING POSTURE OF ROBOT FROM STATE OF ROBOT AND THE LIKE
S30
ACTUAL FLOOR REACTION FORCE DETECTOR
DETECT ACTUAL FLOOR REACTION FORCE OF EACH GROUND CONTACT PORTION
S32
HIERARCHICAL COMPLIANCE OPERATION DETERMINER
SUBROUTINE FOR DETERMINING EACH COMPENSATING ANGLE
S34
CALCULATE DEFORMATION COMPENSATION AMOUNT ON THE BASIS OF DESIRED NODE FLOOR REACTION FORCE
S36
ESTIMATE FLOOR CONFIGURATION ERROR
S37
CORRECT DESIRED GROUND CONTACT PORTION POSITION/POSTURE ON THE BASIS OF COMPENSATING ANGLE AND FLOOR CONFIGURATION ERROR, AND FURTHER CORRECT IT ON THE BASIS OF DEFORMATION COMPENSATION AMOUNT THEREBY TO OBTAIN CORRECTED DESIRED GROUND CONTACT PORTION POSITION/POSTURE WITH DEFORMATION COMPENSATION
S38'
ROBOT GEOMETRIC MODEL
CALCULATE JOINT DISPLACEMENT COMMAND FROM DESIRED BODY POSITION/POSTURE AND CORRECTED DESIRED GROUND CONTACT PORTION POSITION/POSTURE WITH DEFORMATION COMPENSATION
S40
DISPLACEMENT CONTROLLER
MAKE ACTUAL JOINT DISPLACEMENT FOLLOW JOINT DISPLACEMENT COMMAND
S42
t = t + Δt
S44
END

FIG.37

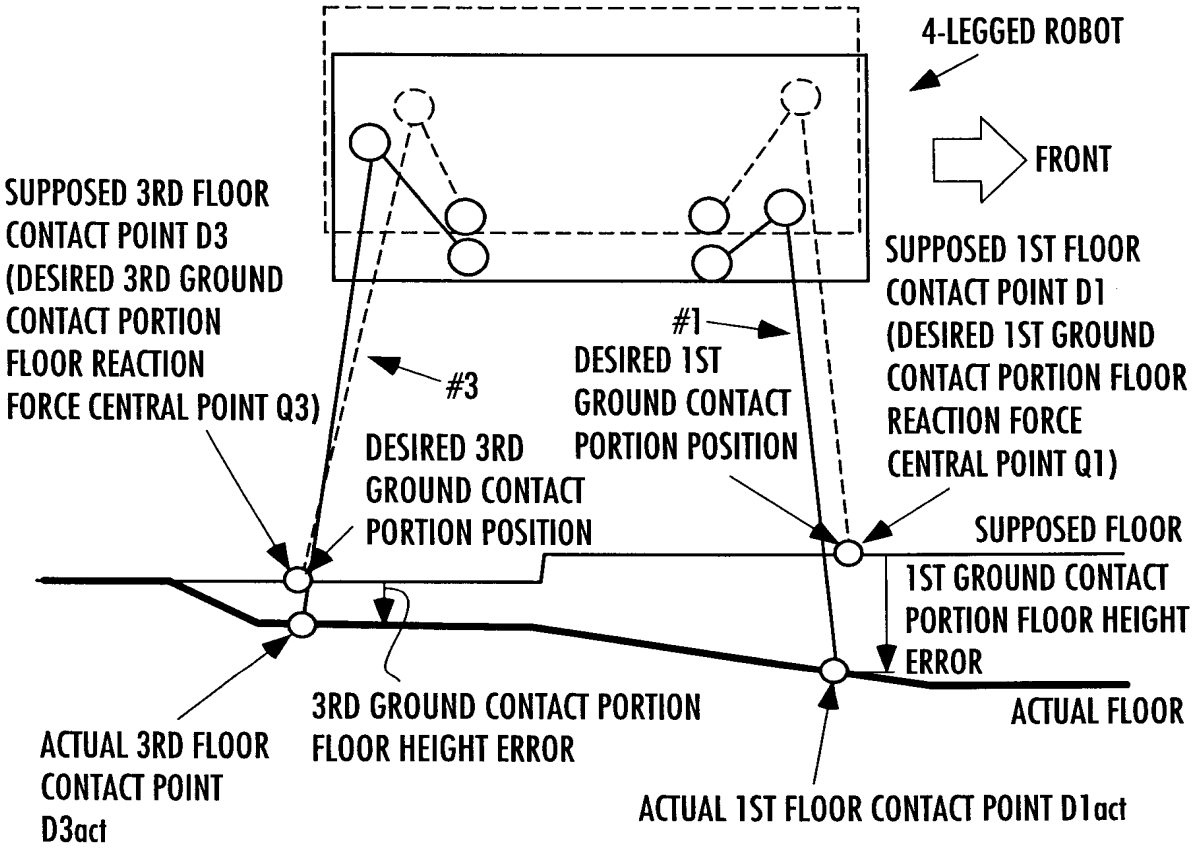

4-LEGGED ROBOT
FRONT
SUPPOSED 3RD FLOOR CONTACT POINT D3 (DESIRED 3RD GROUND CONTACT PORTION FLOOR REACTION FORCE CENTRAL POINT Q3)
#3
DESIRED 3RD GROUND CONTACT PORTION POSITION
#1
DESIRED 1ST GROUND CONTACT PORTION POSITION
SUPPOSED 1ST FLOOR CONTACT POINT D1 (DESIRED 1ST GROUND CONTACT PORTION FLOOR REACTION FORCE CENTRAL POINT Q1)
SUPPOSED FLOOR
1ST GROUND CONTACT PORTION FLOOR HEIGHT ERROR
ACTUAL FLOOR
3RD GROUND CONTACT PORTION FLOOR HEIGHT ERROR
ACTUAL 3RD FLOOR CONTACT POINT D3act
ACTUAL 1ST FLOOR CONTACT POINT D1act

FIG.38

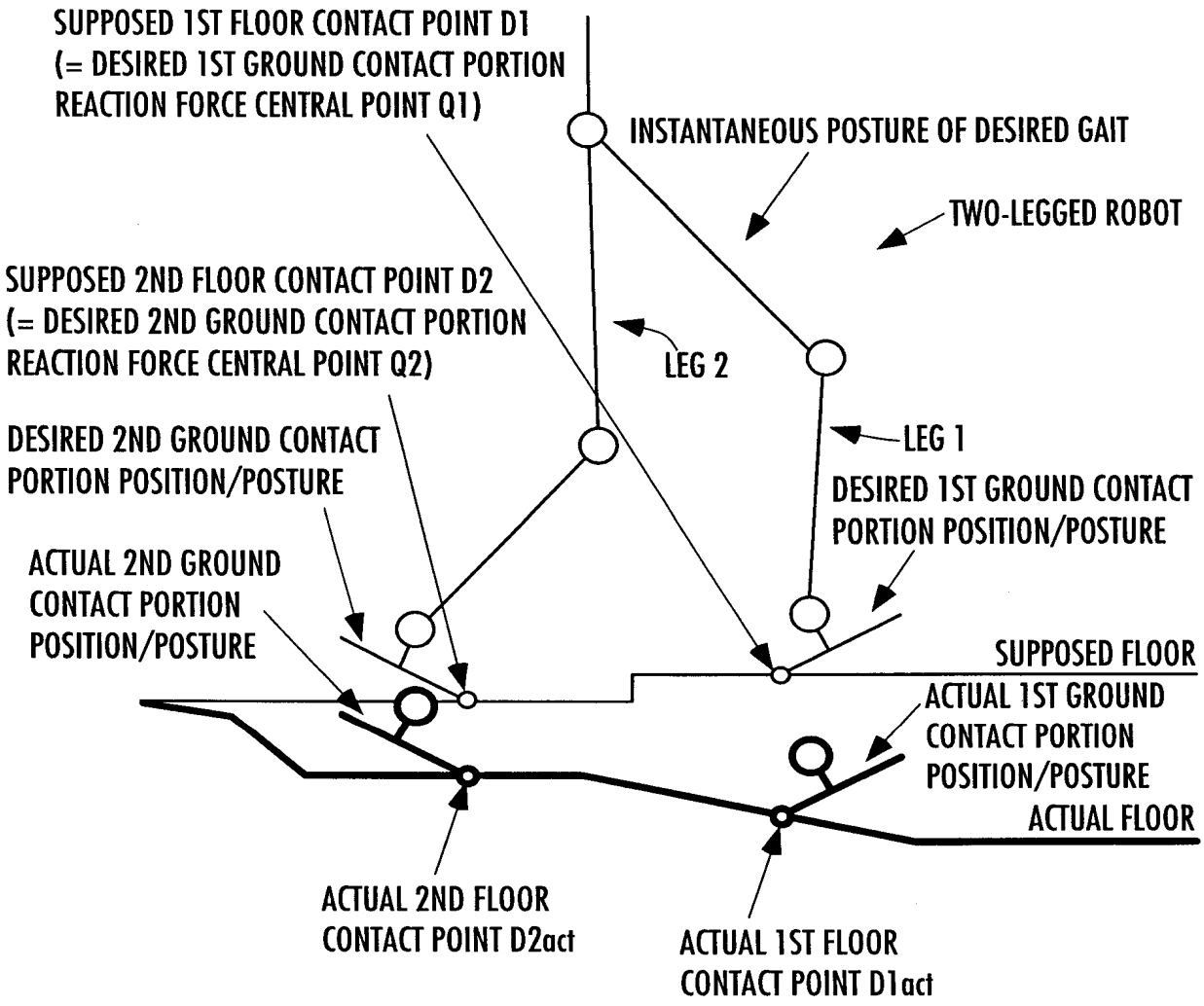

SUPPOSED 1ST FLOOR CONTACT POINT D1
(= DESIRED 1ST GROUND CONTACT PORTION
REACTION FORCE CENTRAL POINT Q1)
INSTANTANEOUS POSTURE OF DESIRED GAIT
TWO-LEGGED ROBOT
SUPPOSED 2ND FLOOR CONTACT POINT D2
(= DESIRED 2ND GROUND CONTACT PORTION
REACTION FORCE CENTRAL POINT Q2)
LEG 2
LEG 1
DESIRED 2ND GROUND CONTACT
PORTION POSITION/POSTURE
DESIRED 1ST GROUND CONTACT
PORTION POSITION/POSTURE
ACTUAL 2ND GROUND
CONTACT PORTION
POSITION/POSTURE
SUPPOSED FLOOR
ACTUAL 1ST GROUND
CONTACT PORTION
POSITION/POSTURE
ACTUAL FLOOR
ACTUAL 2ND FLOOR
CONTACT POINT D2act
ACTUAL 1ST FLOOR
CONTACT POINT D1act

FIG.39

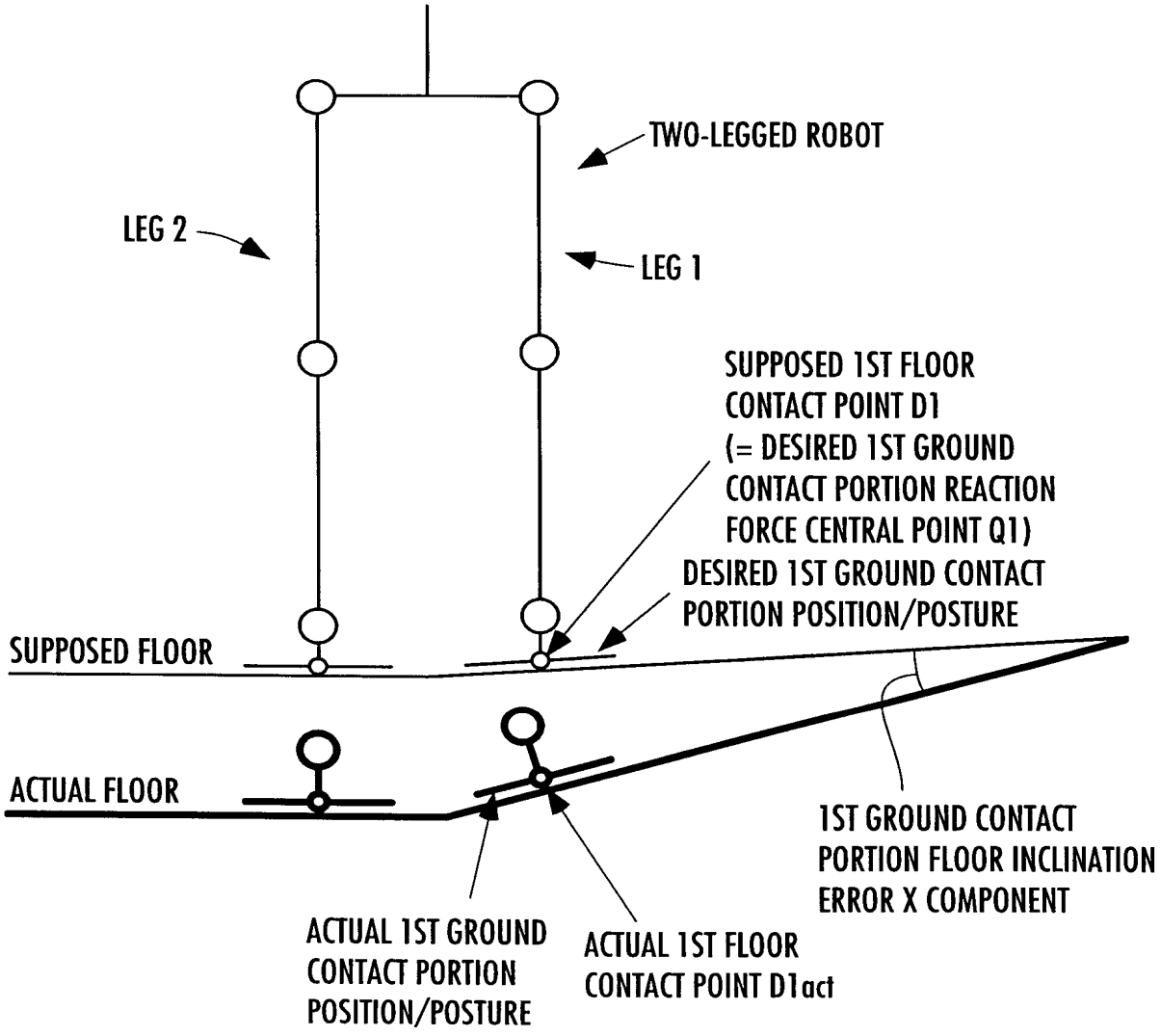

TWO-LEGGED ROBOT
LEG 2
LEG 1
SUPPOSED 1ST FLOOR CONTACT POINT D1 (= DESIRED 1ST GROUND CONTACT PORTION REACTION FORCE CENTRAL POINT Q1)
DESIRED 1ST GROUND CONTACT PORTION POSITION/POSTURE
SUPPOSED FLOOR
ACTUAL FLOOR
1ST GROUND CONTACT PORTION FLOOR INCLINATION ERROR X COMPONENT
ACTUAL 1ST GROUND CONTACT PORTION POSITION/POSTURE
ACTUAL 1ST FLOOR CONTACT POINT D1act

FIG.40

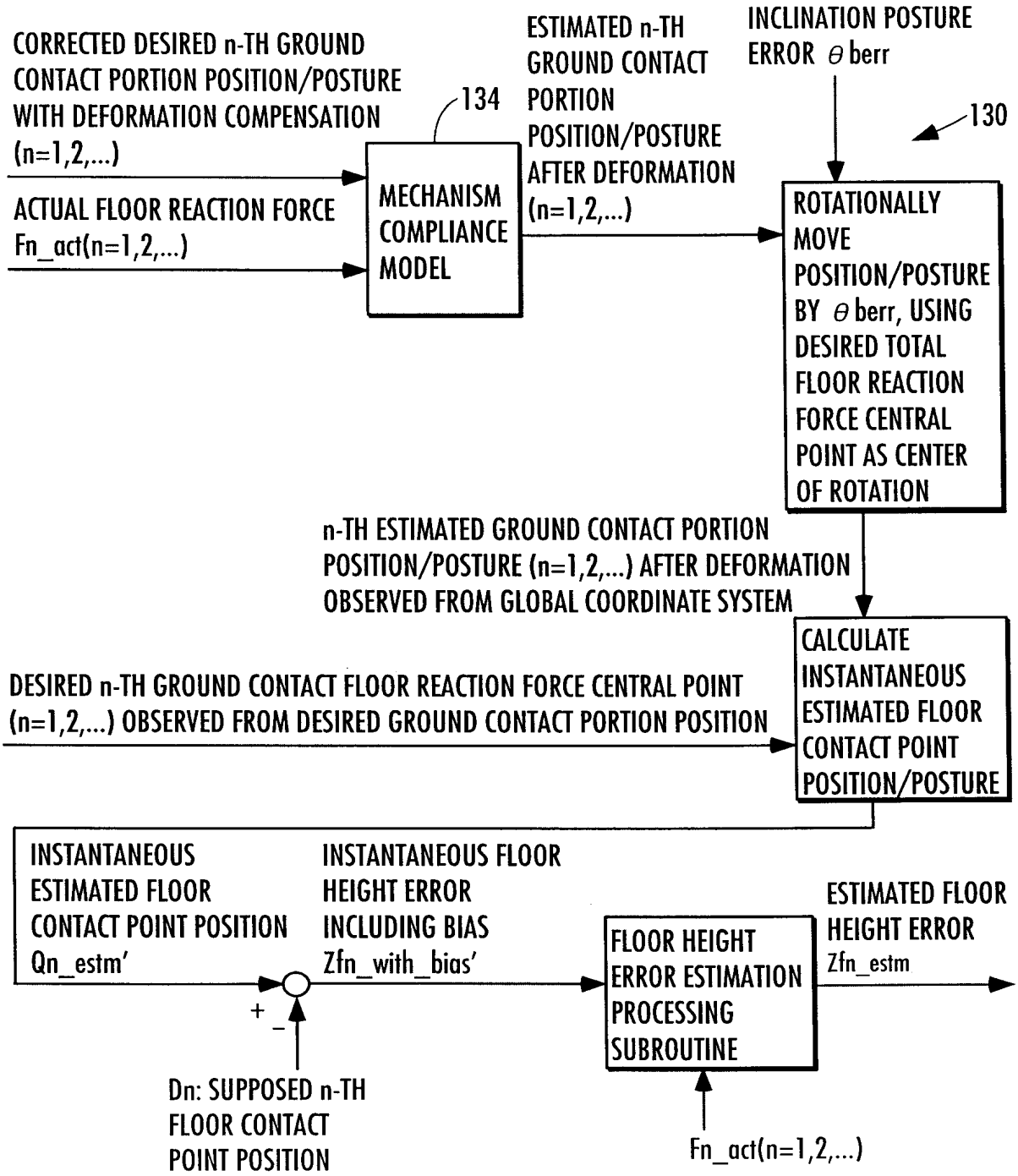

CORRECTED DESIRED n-TH GROUND CONTACT PORTION POSITION/POSTURE WITH DEFORMATION COMPENSATION (n=1,2,...)
ACTUAL FLOOR REACTION FORCE Fn_act(n=1,2,...)
134
MECHANISM COMPLIANCE MODEL
ESTIMATED n-TH GROUND CONTACT PORTION POSITION/POSTURE AFTER DEFORMATION (n=1,2,...)
INCLINATION POSTURE ERROR θberr
130
ROTATIONALLY MOVE POSITION/POSTURE BY θberr, USING DESIRED TOTAL FLOOR REACTION FORCE CENTRAL POINT AS CENTER OF ROTATION
n-TH ESTIMATED GROUND CONTACT PORTION POSITION/POSTURE (n=1,2,...) AFTER DEFORMATION OBSERVED FROM GLOBAL COORDINATE SYSTEM
CALCULATE INSTANTANEOUS ESTIMATED FLOOR CONTACT POINT POSITION/POSTURE
DESIRED n-TH GROUND CONTACT FLOOR REACTION FORCE CENTRAL POINT (n=1,2,...) OBSERVED FROM DESIRED GROUND CONTACT PORTION POSITION
INSTANTANEOUS ESTIMATED FLOOR CONTACT POINT POSITION Qn_estm'
INSTANTANEOUS FLOOR HEIGHT ERROR INCLUDING BIAS Zfn_with_bias'
+
−
Dn: SUPPOSED n-TH FLOOR CONTACT POINT POSITION
FLOOR HEIGHT ERROR ESTIMATION PROCESSING SUBROUTINE
ESTIMATED FLOOR HEIGHT ERROR Zfn_estm
Fn_act(n=1,2,...)

FIG.41

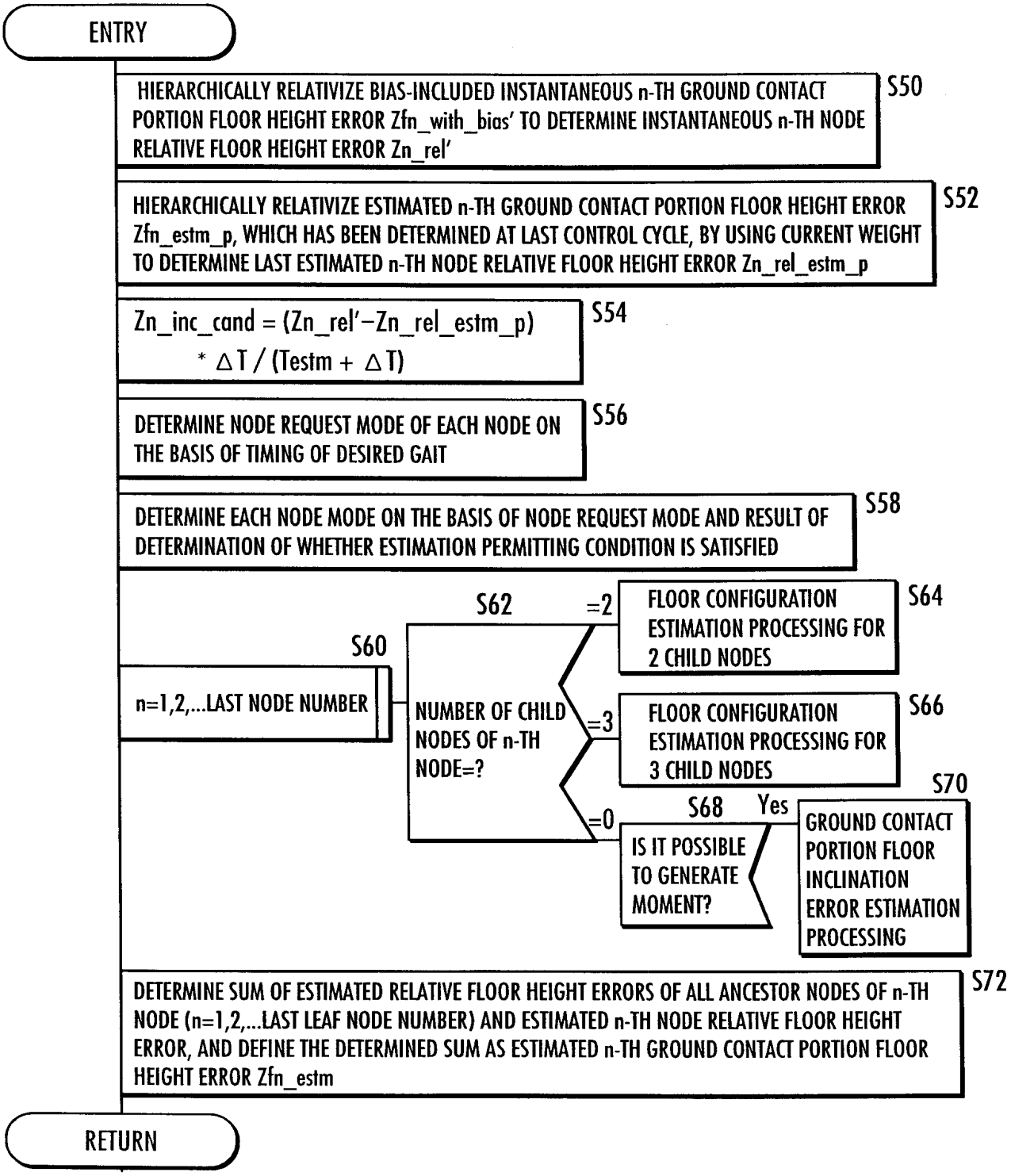
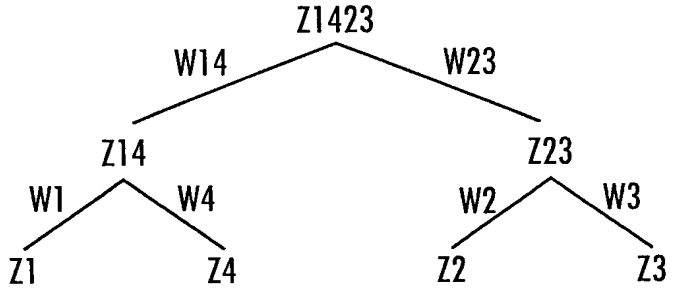

ENTRY
HIERARCHICALLY RELATIVIZE BIAS-INCLUDED INSTANTANEOUS n-TH GROUND CONTACT PORTION FLOOR HEIGHT ERROR Zfn_with_bias' TO DETERMINE INSTANTANEOUS n-TH NODE RELATIVE FLOOR HEIGHT ERROR Zn_rel'
S50
HIERARCHICALLY RELATIVIZE ESTIMATED n-TH GROUND CONTACT PORTION FLOOR HEIGHT ERROR Zfn_estm_p, WHICH HAS BEEN DETERMINED AT LAST CONTROL CYCLE, BY USING CURRENT WEIGHT TO DETERMINE LAST ESTIMATED n-TH NODE RELATIVE FLOOR HEIGHT ERROR Zn_rel_estm_p
S52
Zn_inc_cand = (Zn_rel'−Zn_rel_estm_p) * ΔT / (Testm + ΔT)
S54
DETERMINE NODE REQUEST MODE OF EACH NODE ON THE BASIS OF TIMING OF DESIRED GAIT
S56
DETERMINE EACH NODE MODE ON THE BASIS OF NODE REQUEST MODE AND RESULT OF DETERMINATION OF WHETHER ESTIMATION PERMITTING CONDITION IS SATISFIED
S58
S60
n=1,2,...LAST NODE NUMBER
S62
NUMBER OF CHILD NODES OF n-TH NODE=?
=2
FLOOR CONFIGURATION ESTIMATION PROCESSING FOR 2 CHILD NODES
S64
=3
FLOOR CONFIGURATION ESTIMATION PROCESSING FOR 3 CHILD NODES
S66
=0
S68
IS IT POSSIBLE TO GENERATE MOMENT?
Yes
S70
GROUND CONTACT PORTION FLOOR INCLINATION ERROR ESTIMATION PROCESSING
DETERMINE SUM OF ESTIMATED RELATIVE FLOOR HEIGHT ERRORS OF ALL ANCESTOR NODES OF n-TH NODE (n=1,2,...LAST LEAF NODE NUMBER) AND ESTIMATED n-TH NODE RELATIVE FLOOR HEIGHT ERROR, AND DEFINE THE DETERMINED SUM AS ESTIMATED n-TH GROUND CONTACT PORTION FLOOR HEIGHT ERROR Zfn_estm
S72
RETURN

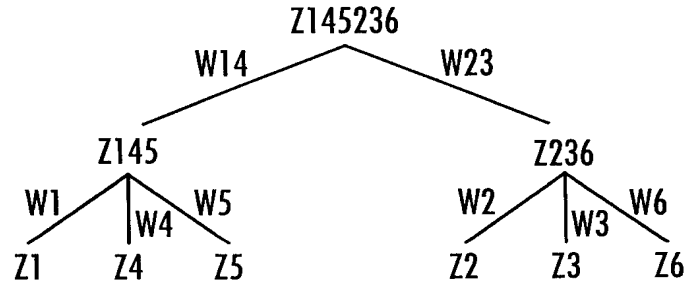
FIG.42



$Z14_with_bias = W1 \cdot Z1_with_bias + W4 \cdot Z4_with_bias$
$Z23_with_bias = W2 \cdot Z2_with_bias + W3 \cdot Z3_with_bias$
$Z1423_with_bias = W14 \cdot Z14_with_bias + W23 \cdot Z23_with_bias$

$Z1_rel = Z1_with_bias - Z14_with_bias$
$Z4_rel = Z4_with_bias - Z14_with_bias$
$Z2_rel = Z2_with_bias - Z23_with_bias$
$Z3_rel = Z3_with_bias - Z23_with_bias$
$Z14_rel = Z14_with_bias - Z1423_with_bias$
$Z23_rel = Z23_with_bias - Z1423_with_bias$

FIG.43



$Z145_with_bias = W1 \cdot Z1_with_bias + W4 \cdot Z4_with_bias + W5 \cdot Z5_with_bias$
$Z236_with_bias = W2 \cdot Z2_with_bias + W3 \cdot Z3_with_bias + W6 \cdot Z6_with_bias$
$Z145236_with_bias = W145 \cdot Z145_with_bias + W236 \cdot Z236_with_bias$

$Z1_rel = Z1_with_bias - Z145_with_bias$
$Z4_rel = Z4_with_bias - Z145_with_bias$
$Z5_rel = Z5_with_bias - Z145_with_bias$
$Z2_rel = Z2_with_bias - Z236_with_bias$
$Z3_rel = Z3_with_bias - Z236_with_bias$
$Z6_rel = Z6_with_bias - Z236_with_bias$
$Z145_rel = Z145_with_bias - Z145236_with_bias$
$Z236_rel = Z236_with_bias - Z145236_with_bias$

FIG.44

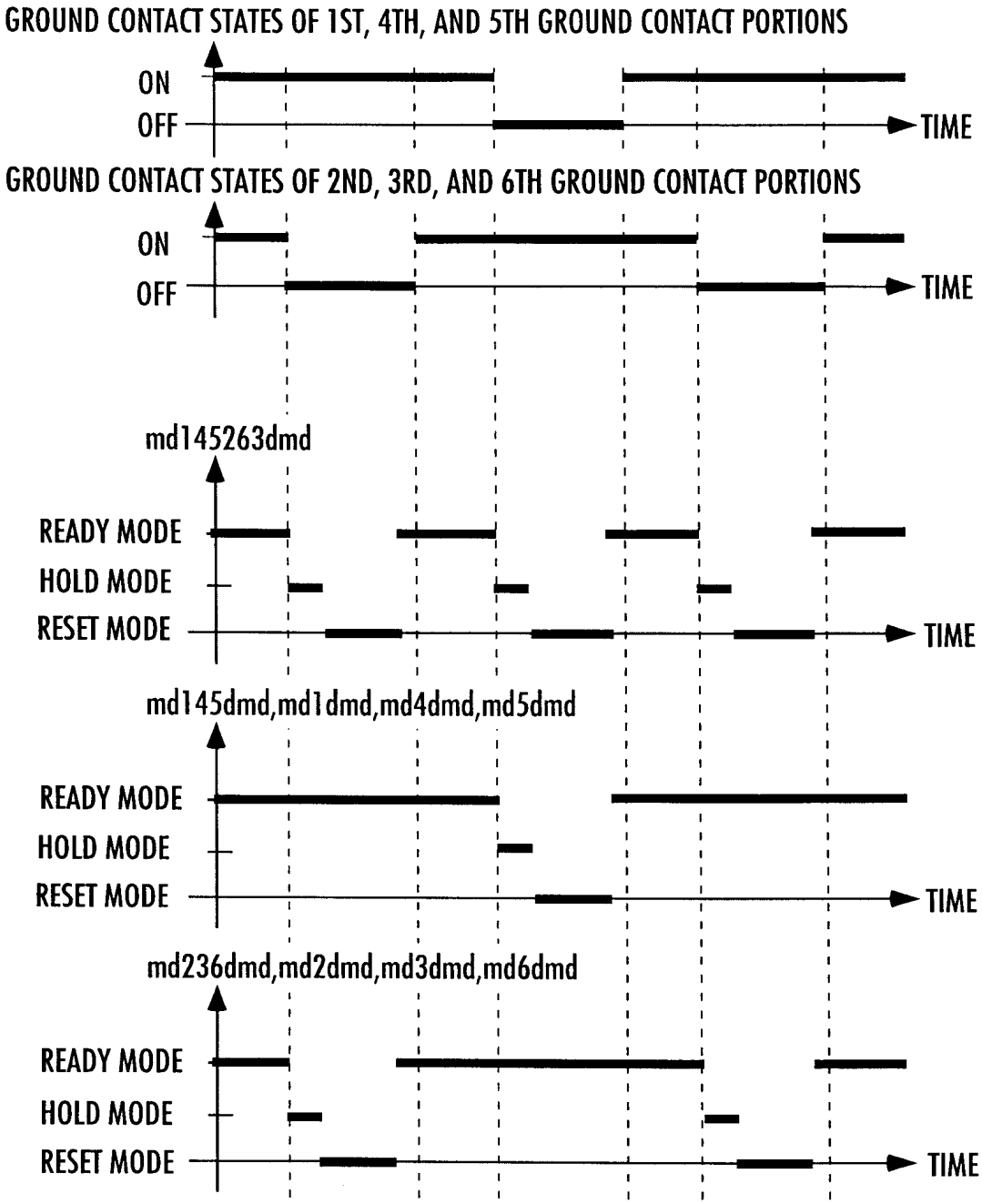

GROUND CONTACT STATES OF 1ST, 4TH, AND 5TH GROUND CONTACT PORTIONS
ON
OFF
TIME
GROUND CONTACT STATES OF 2ND, 3RD, AND 6TH GROUND CONTACT PORTIONS
ON
OFF
TIME
md145263dmd
READY MODE
HOLD MODE
RESET MODE
TIME
md145dmd,md1dmd,md4dmd,md5dmd
READY MODE
HOLD MODE
RESET MODE
TIME
md236dmd,md2dmd,md3dmd,md6dmd
READY MODE
HOLD MODE
RESET MODE
TIME

FIG.45

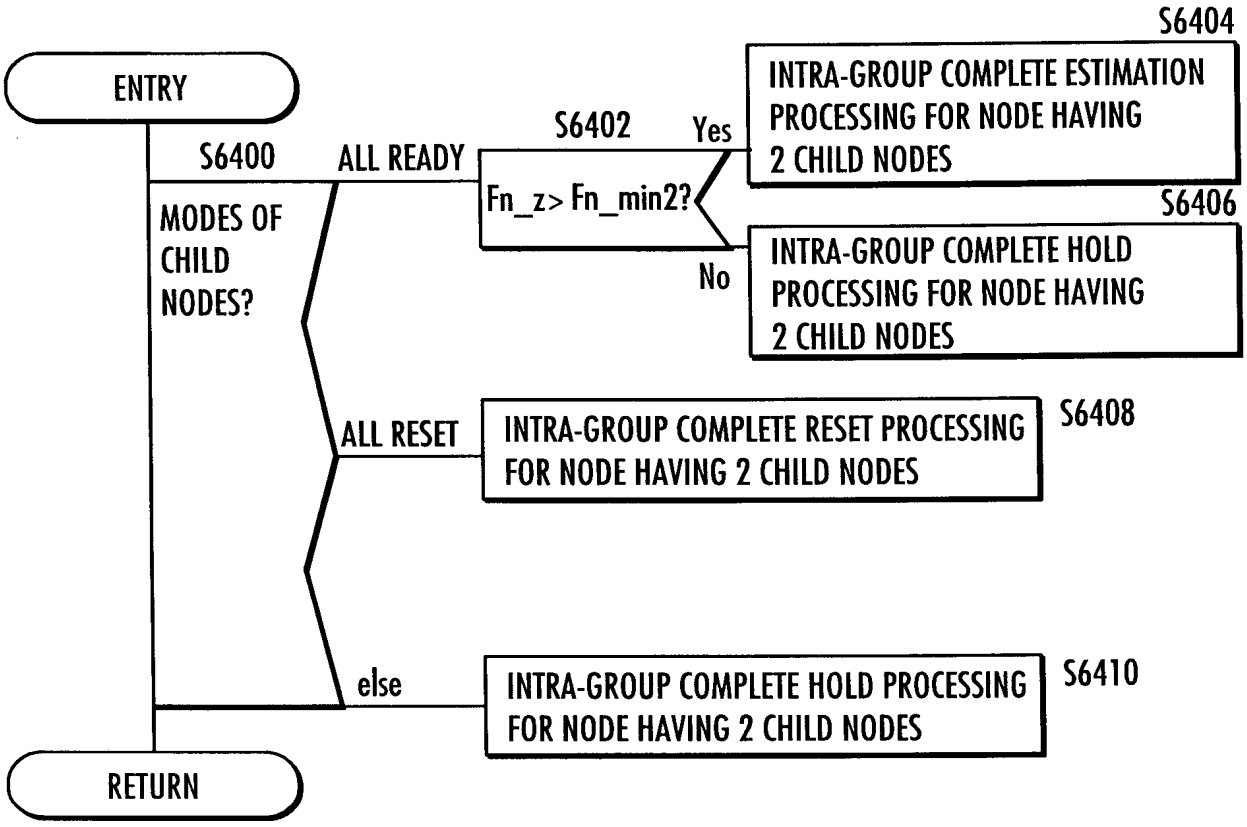

ENTRY
S6400
MODES OF CHILD NODES?
ALL READY
S6402
Fn_z> Fn_min2?
Yes
No
S6404
INTRA-GROUP COMPLETE ESTIMATION PROCESSING FOR NODE HAVING 2 CHILD NODES
S6406
INTRA-GROUP COMPLETE HOLD PROCESSING FOR NODE HAVING 2 CHILD NODES
ALL RESET
INTRA-GROUP COMPLETE RESET PROCESSING FOR NODE HAVING 2 CHILD NODES
S6408
else
INTRA-GROUP COMPLETE HOLD PROCESSING FOR NODE HAVING 2 CHILD NODES
S6410
RETURN

FIG.46

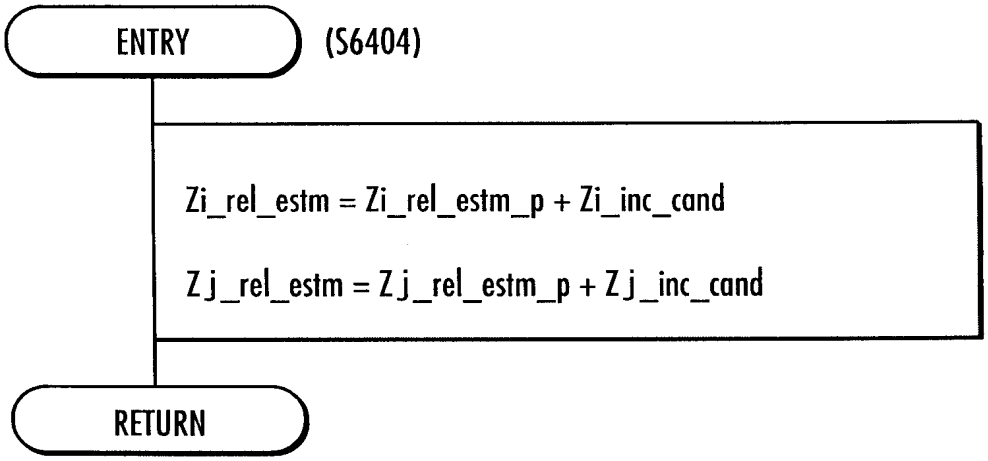


FIG.47

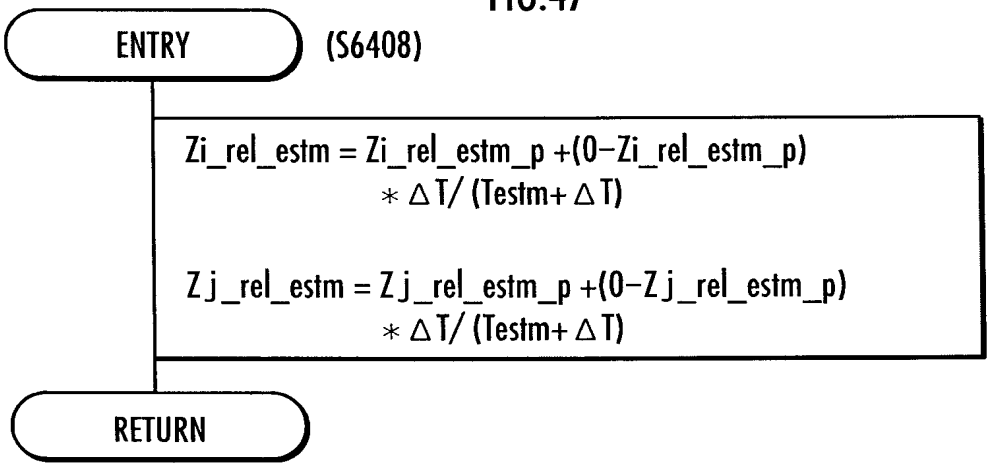


FIG.48

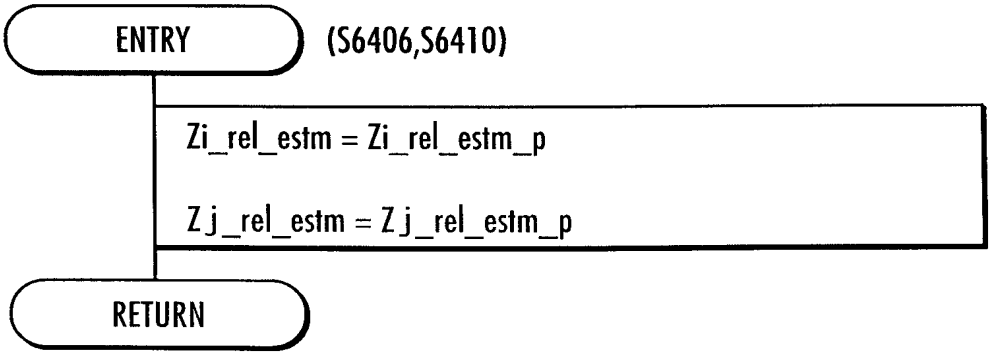


FIG.49

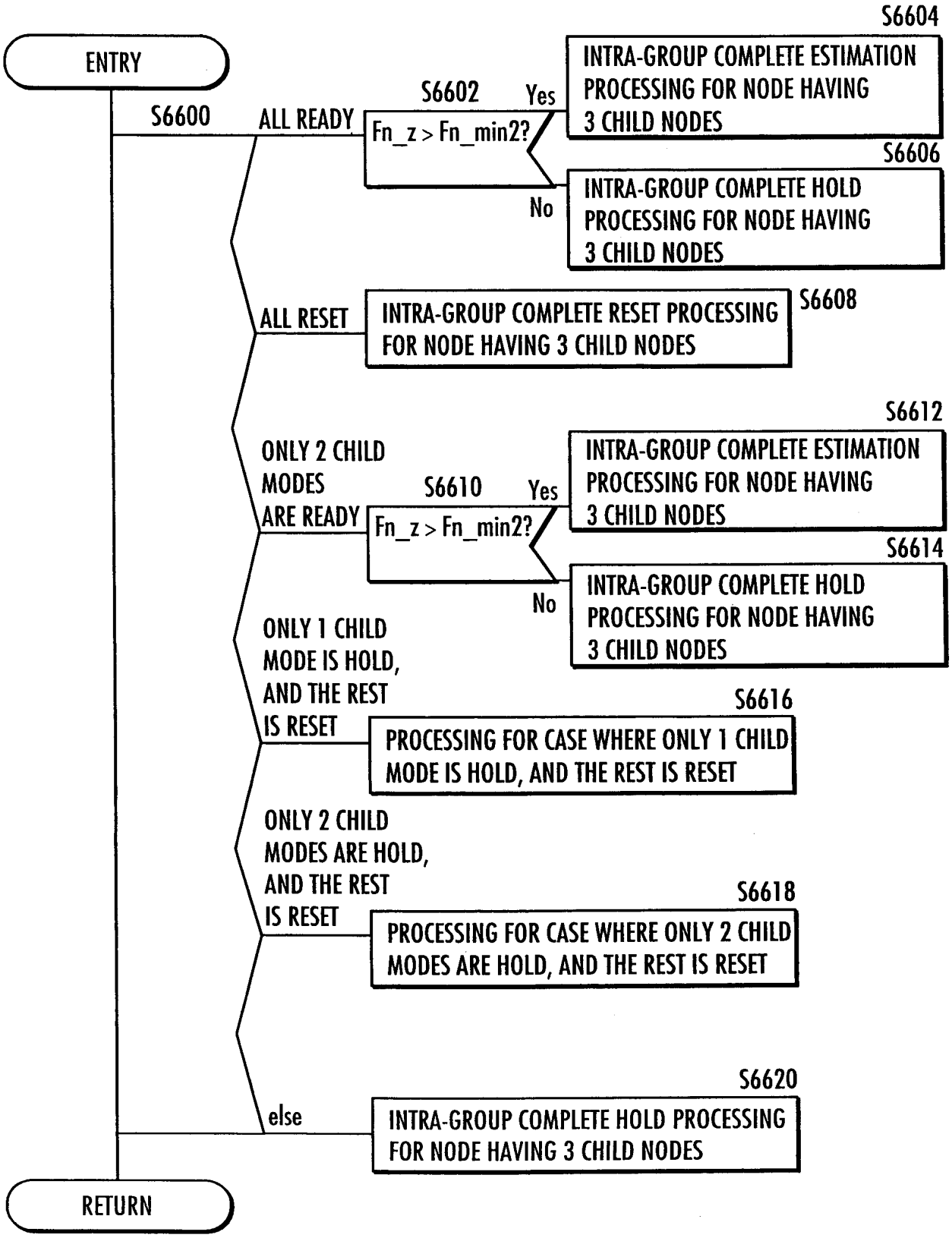

ENTRY
S6600
ALL READY
S6602
Fn_z > Fn_min2?
Yes
No
S6604
INTRA-GROUP COMPLETE ESTIMATION PROCESSING FOR NODE HAVING 3 CHILD NODES
S6606
INTRA-GROUP COMPLETE HOLD PROCESSING FOR NODE HAVING 3 CHILD NODES
ALL RESET
INTRA-GROUP COMPLETE RESET PROCESSING FOR NODE HAVING 3 CHILD NODES
S6608
ONLY 2 CHILD MODES ARE READY
S6610
Fn_z > Fn_min2?
Yes
No
S6612
INTRA-GROUP COMPLETE ESTIMATION PROCESSING FOR NODE HAVING 3 CHILD NODES
S6614
INTRA-GROUP COMPLETE HOLD PROCESSING FOR NODE HAVING 3 CHILD NODES
ONLY 1 CHILD MODE IS HOLD, AND THE REST IS RESET
S6616
PROCESSING FOR CASE WHERE ONLY 1 CHILD MODE IS HOLD, AND THE REST IS RESET
ONLY 2 CHILD MODES ARE HOLD, AND THE REST IS RESET
S6618
PROCESSING FOR CASE WHERE ONLY 2 CHILD MODES ARE HOLD, AND THE REST IS RESET
else
S6620
INTRA-GROUP COMPLETE HOLD PROCESSING FOR NODE HAVING 3 CHILD NODES
RETURN

FIG.50

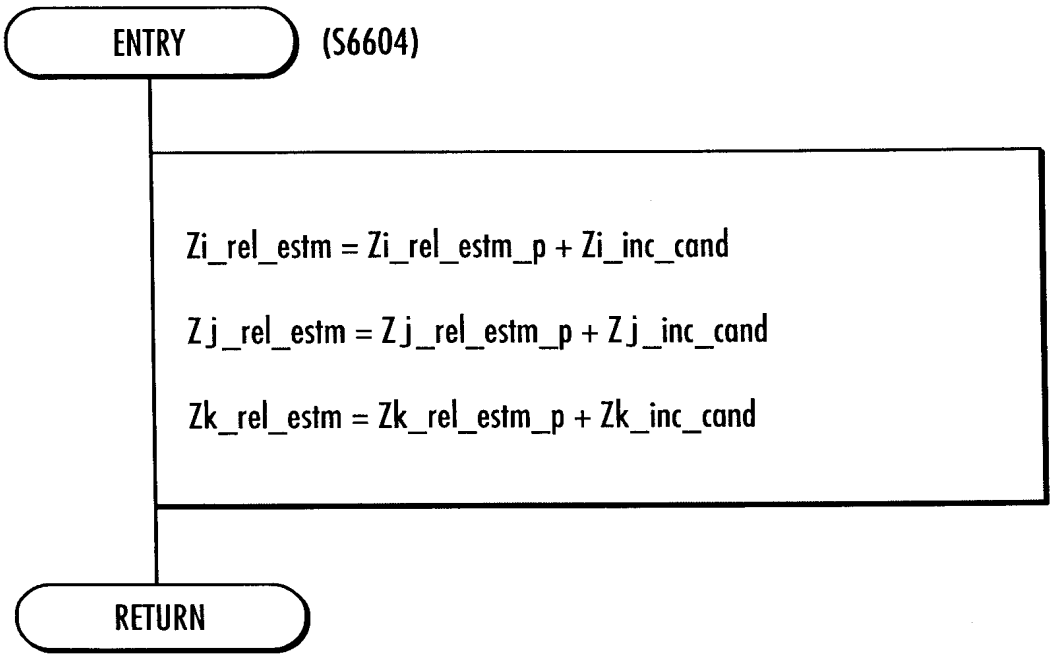

ENTRY
(S6604)
Zi_rel_estm = Zi_rel_estm_p + Zi_inc_cand
Zj_rel_estm = Zj_rel_estm_p + Zj_inc_cand
Zk_rel_estm = Zk_rel_estm_p + Zk_inc_cand
RETURN

FIG.51

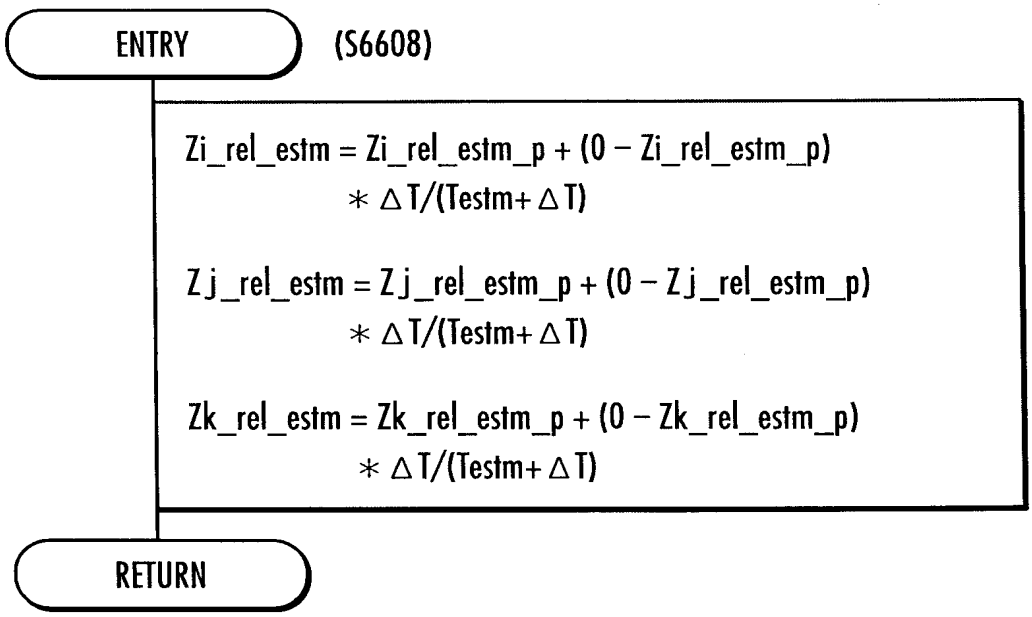

ENTRY
(S6608)
Zi_rel_estm = Zi_rel_estm_p + (0 − Zi_rel_estm_p)
∗ ΔT/(Testm+ΔT)
Zj_rel_estm = Zj_rel_estm_p + (0 − Zj_rel_estm_p)
∗ ΔT/(Testm+ΔT)
Zk_rel_estm = Zk_rel_estm_p + (0 − Zk_rel_estm_p)
∗ ΔT/(Testm+ΔT)
RETURN

FIG.52

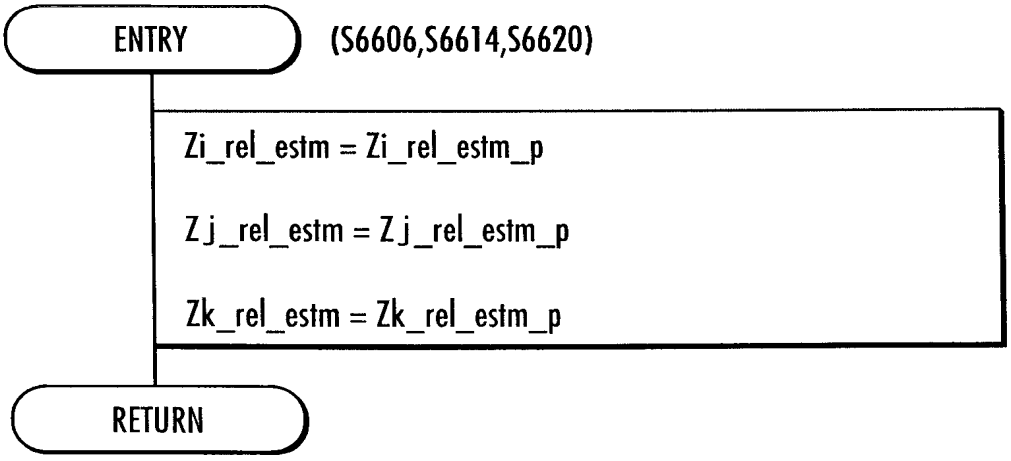

ENTRY
(S6606,S6614,S6620)
Zi_rel_estm = Zi_rel_estm_p
Zj_rel_estm = Zj_rel_estm_p
Zk_rel_estm = Zk_rel_estm_p
RETURN

FIG.53

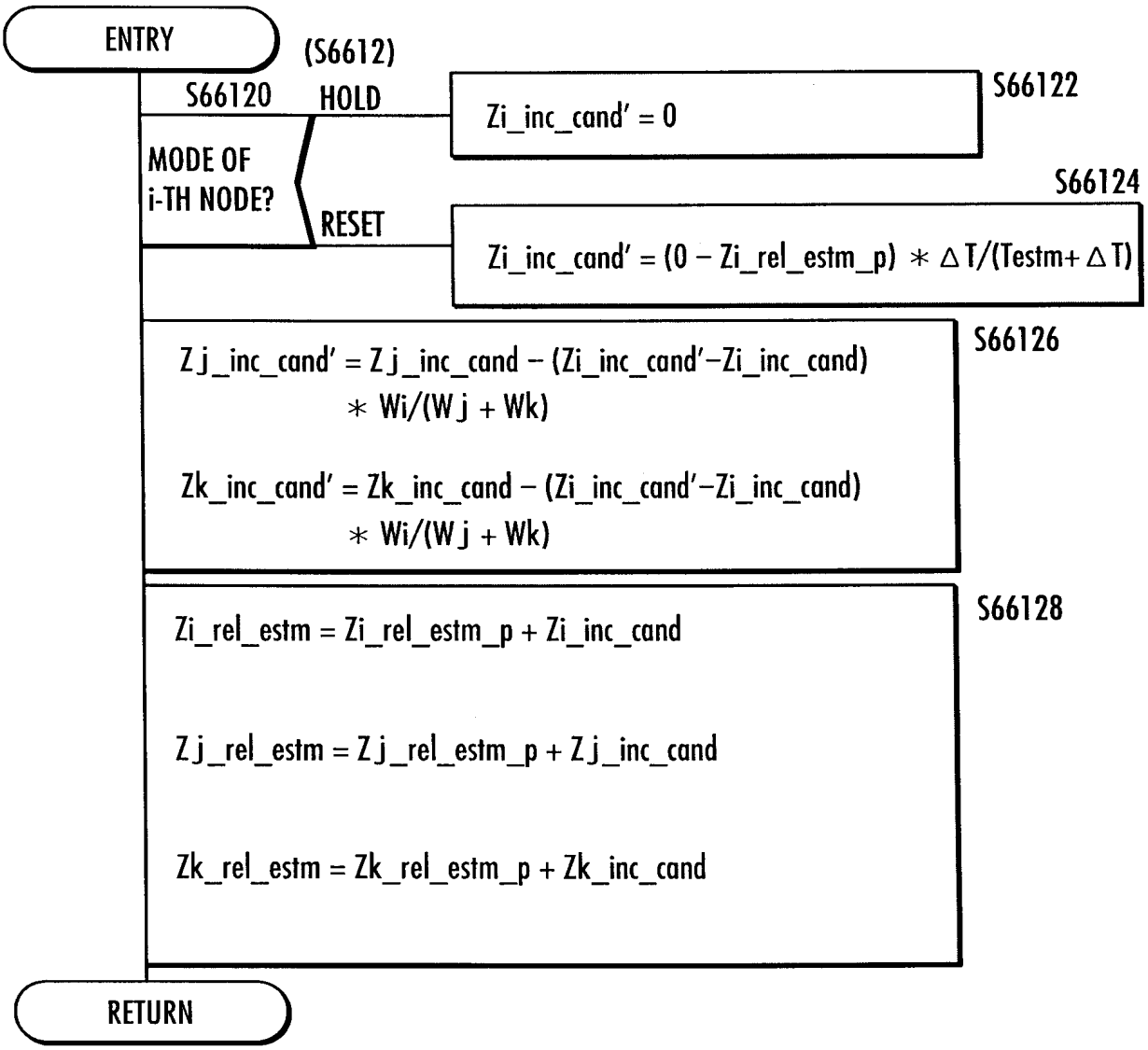

ENTRY
(S6612)
S66120
HOLD
MODE OF i-TH NODE?
RESET
Zi_inc_cand' = 0
S66122
Zi_inc_cand' = (0 − Zi_rel_estm_p) ∗ ΔT/(Testm+ΔT)
S66124
Zj_inc_cand' = Zj_inc_cand − (Zi_inc_cand'−Zi_inc_cand) ∗ Wi/(Wj + Wk)
Zk_inc_cand' = Zk_inc_cand − (Zi_inc_cand'−Zi_inc_cand) ∗ Wi/(Wj + Wk)
S66126
Zi_rel_estm = Zi_rel_estm_p + Zi_inc_cand
Zj_rel_estm = Zj_rel_estm_p + Zj_inc_cand
Zk_rel_estm = Zk_rel_estm_p + Zk_inc_cand
S66128
RETURN

FIG.54

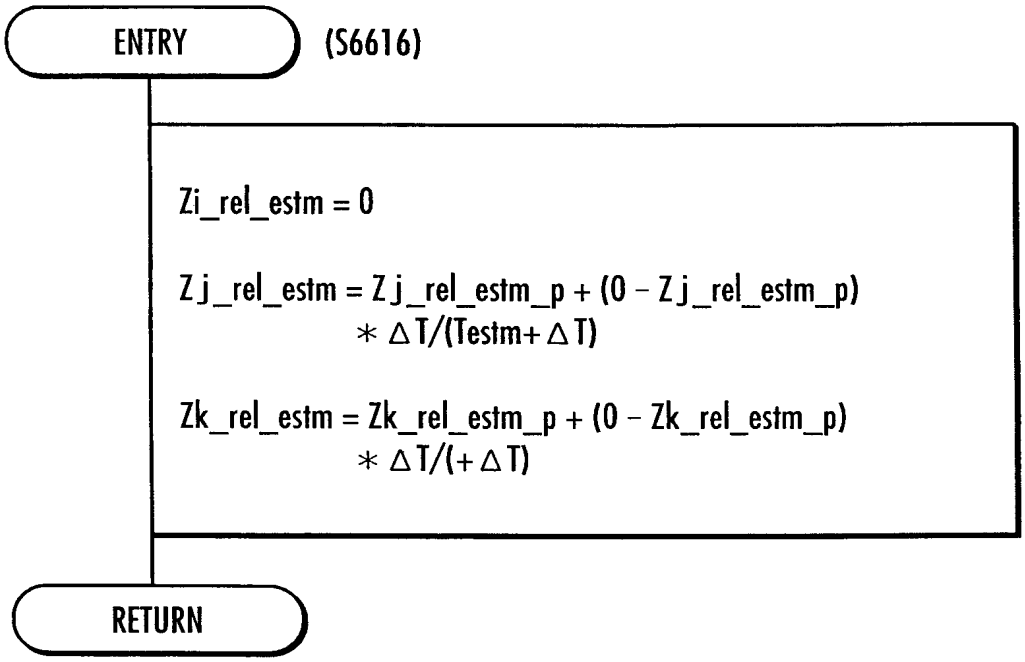

ENTRY
(S6616)
Zi_rel_estm = 0
Zj_rel_estm = Zj_rel_estm_p + (0 − Zj_rel_estm_p) * ΔT/(Testm+ΔT)
Zk_rel_estm = Zk_rel_estm_p + (0 − Zk_rel_estm_p) * ΔT/(+ΔT)
RETURN

FIG.55

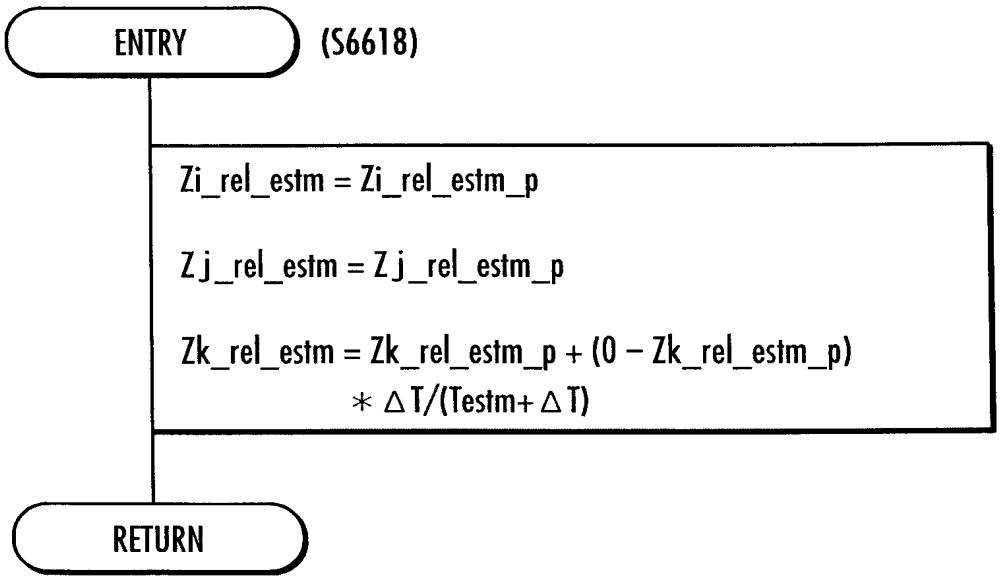

ENTRY
(S6618)
Zi_rel_estm = Zi_rel_estm_p
Zj_rel_estm = Zj_rel_estm_p
Zk_rel_estm = Zk_rel_estm_p + (0 − Zk_rel_estm_p)
∗ ΔT/(Testm+ΔT)
RETURN

FIG.56

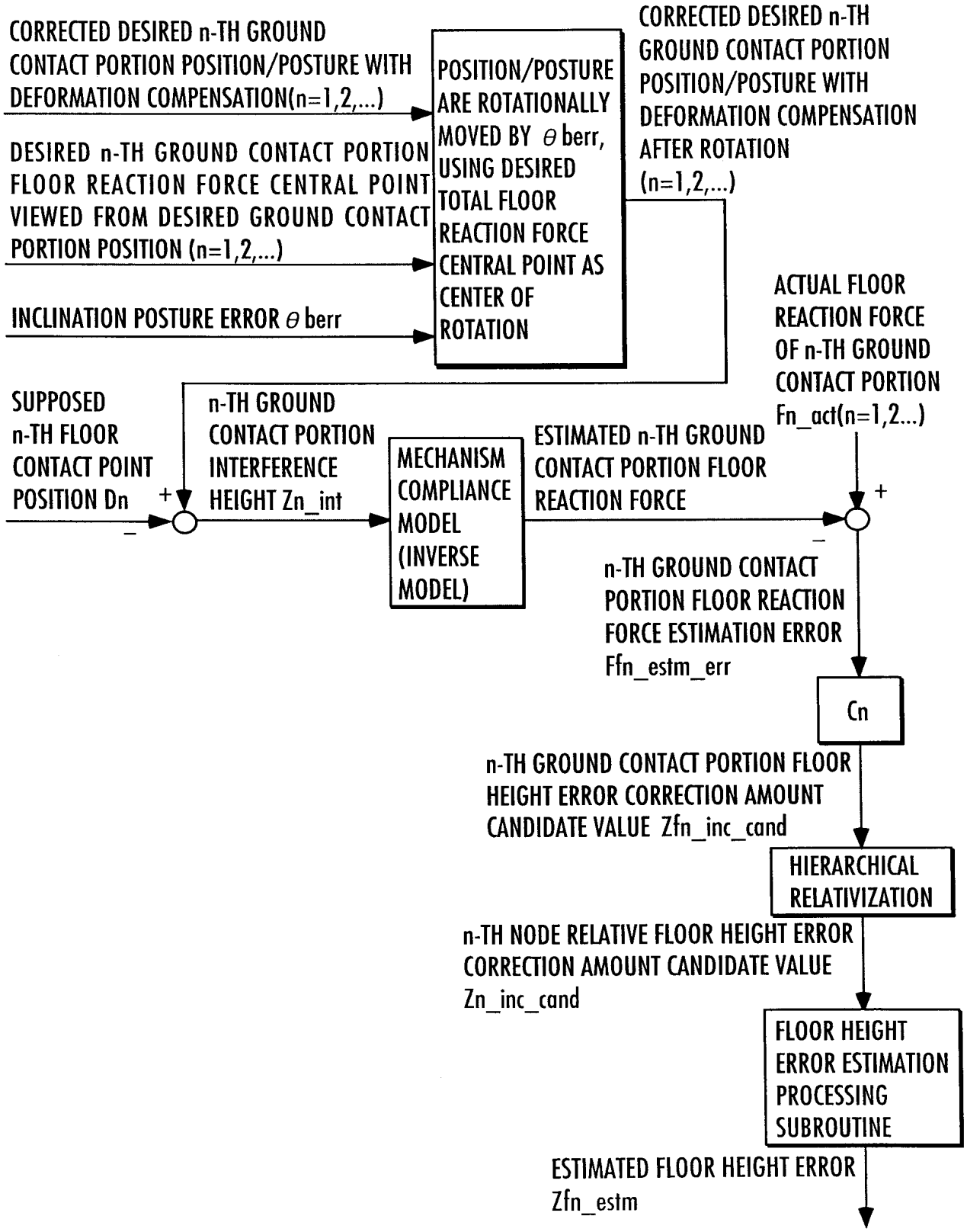

CORRECTED DESIRED n-TH GROUND CONTACT PORTION POSITION/POSTURE WITH DEFORMATION COMPENSATION(n=1,2,...)
DESIRED n-TH GROUND CONTACT PORTION FLOOR REACTION FORCE CENTRAL POINT VIEWED FROM DESIRED GROUND CONTACT PORTION POSITION (n=1,2,...)
INCLINATION POSTURE ERROR θ berr
POSITION/POSTURE ARE ROTATIONALLY MOVED BY θ berr, USING DESIRED TOTAL FLOOR REACTION FORCE CENTRAL POINT AS CENTER OF ROTATION
CORRECTED DESIRED n-TH GROUND CONTACT PORTION POSITION/POSTURE WITH DEFORMATION COMPENSATION AFTER ROTATION (n=1,2,...)
SUPPOSED n-TH FLOOR CONTACT POINT POSITION Dn
n-TH GROUND CONTACT PORTION INTERFERENCE HEIGHT Zn_int
MECHANISM COMPLIANCE MODEL (INVERSE MODEL)
ESTIMATED n-TH GROUND CONTACT PORTION FLOOR REACTION FORCE
ACTUAL FLOOR REACTION FORCE OF n-TH GROUND CONTACT PORTION Fn_act(n=1,2...)
n-TH GROUND CONTACT PORTION FLOOR REACTION FORCE ESTIMATION ERROR Ffn_estm_err
Cn
n-TH GROUND CONTACT PORTION FLOOR HEIGHT ERROR CORRECTION AMOUNT CANDIDATE VALUE Zfn_inc_cand
HIERARCHICAL RELATIVIZATION
n-TH NODE RELATIVE FLOOR HEIGHT ERROR CORRECTION AMOUNT CANDIDATE VALUE Zn_inc_cand
FLOOR HEIGHT ERROR ESTIMATION PROCESSING SUBROUTINE
ESTIMATED FLOOR HEIGHT ERROR Zfn_estm

FIG.57

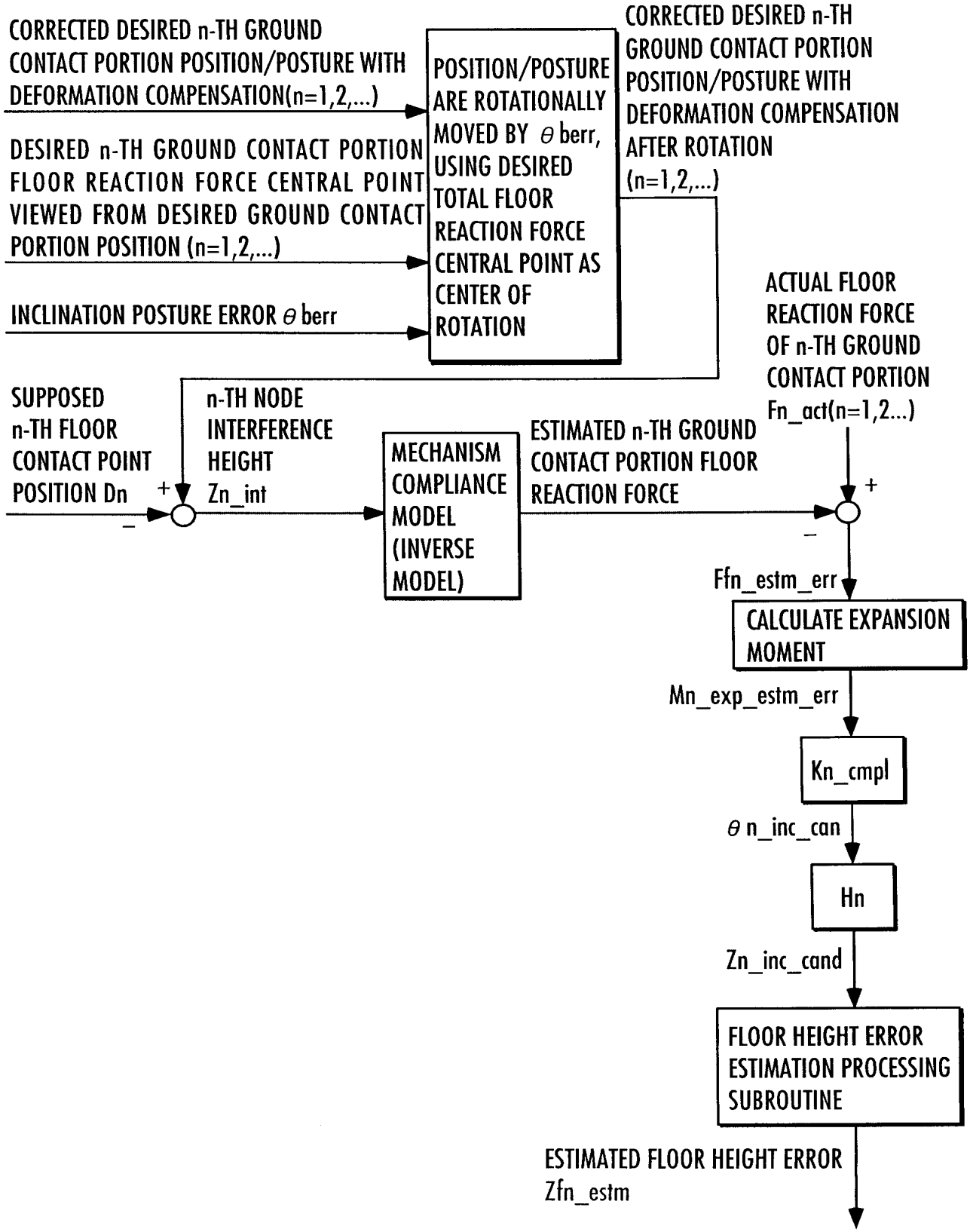

CORRECTED DESIRED n-TH GROUND CONTACT PORTION POSITION/POSTURE WITH DEFORMATION COMPENSATION(n=1,2,...)
DESIRED n-TH GROUND CONTACT PORTION FLOOR REACTION FORCE CENTRAL POINT VIEWED FROM DESIRED GROUND CONTACT PORTION POSITION (n=1,2,...)
INCLINATION POSTURE ERROR θberr
POSITION/POSTURE ARE ROTATIONALLY MOVED BY θberr, USING DESIRED TOTAL FLOOR REACTION FORCE CENTRAL POINT AS CENTER OF ROTATION
CORRECTED DESIRED n-TH GROUND CONTACT PORTION POSITION/POSTURE WITH DEFORMATION COMPENSATION AFTER ROTATION (n=1,2,...)
SUPPOSED n-TH FLOOR CONTACT POINT POSITION Dn
n-TH NODE INTERFERENCE HEIGHT Zn_int
MECHANISM COMPLIANCE MODEL (INVERSE MODEL)
ESTIMATED n-TH GROUND CONTACT PORTION FLOOR REACTION FORCE
ACTUAL FLOOR REACTION FORCE OF n-TH GROUND CONTACT PORTION Fn_act(n=1,2...)
Ffn_estm_err
CALCULATE EXPANSION MOMENT
Mn_exp_estm_err
Kn_cmpl
θn_inc_can
Hn
Zn_inc_cand
FLOOR HEIGHT ERROR ESTIMATION PROCESSING SUBROUTINE
ESTIMATED FLOOR HEIGHT ERROR Zfn_estm

FIG.58

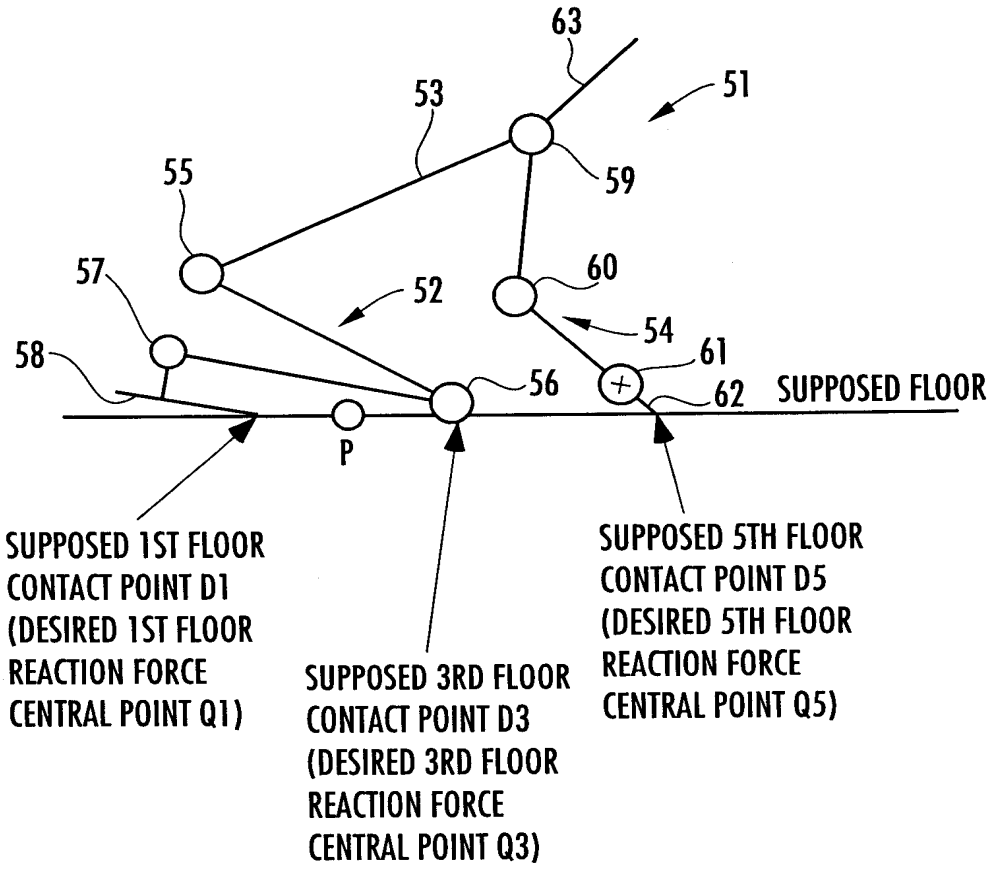

63
51
53
55
59
57
52
60
54
58
61
56
62
SUPPOSED FLOOR
P
SUPPOSED 1ST FLOOR CONTACT POINT D1 (DESIRED 1ST FLOOR REACTION FORCE CENTRAL POINT Q1)
SUPPOSED 3RD FLOOR CONTACT POINT D3 (DESIRED 3RD FLOOR REACTION FORCE CENTRAL POINT Q3)
SUPPOSED 5TH FLOOR CONTACT POINT D5 (DESIRED 5TH FLOOR REACTION FORCE CENTRAL POINT Q5)

FIG.59

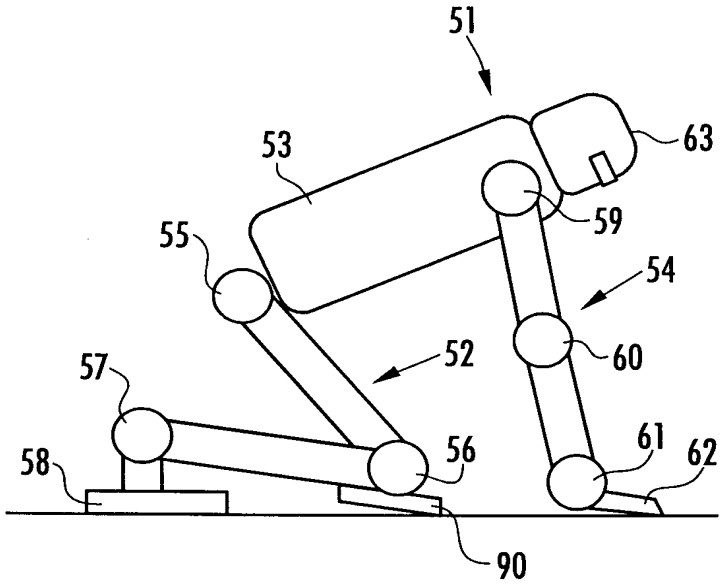


FIG.60

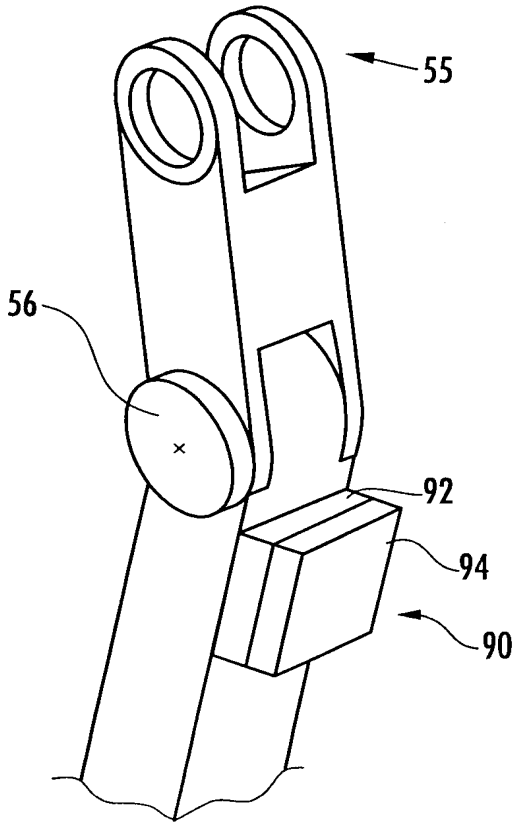
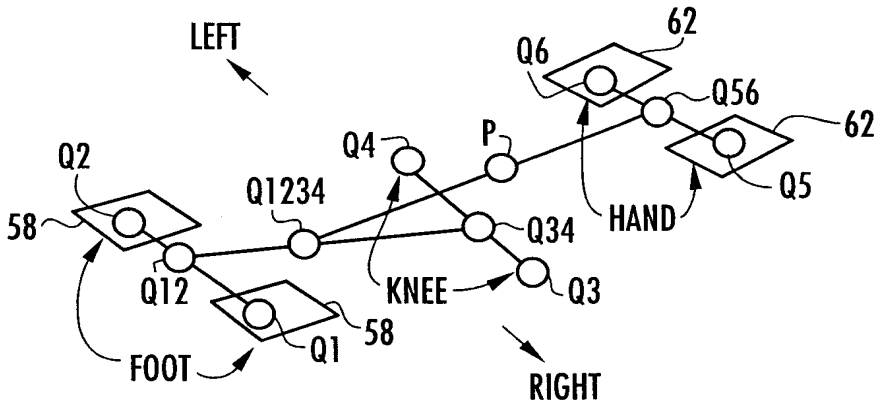


FIG.61


LEFT
62
Q6
Q56
62
Q4
P
Q2
Q1234
Q5
58
HAND
Q34
Q12
KNEE
Q3
58
Q1
FOOT
RIGHT

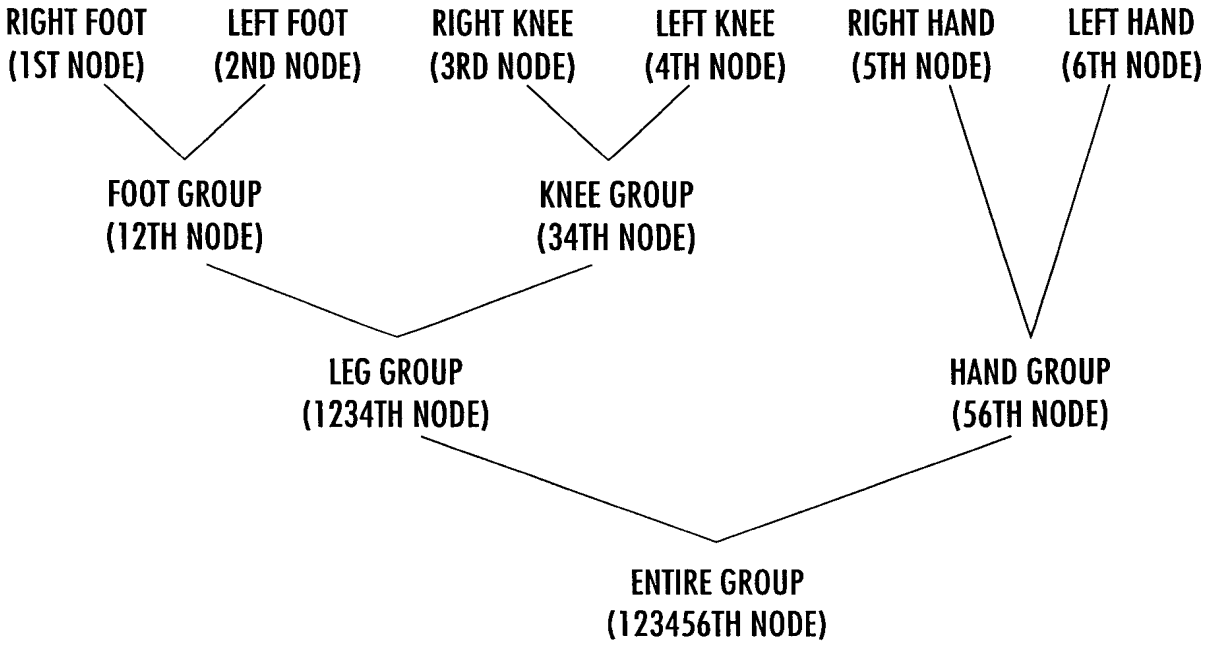

RIGHT FOOT (1ST NODE)
LEFT FOOT (2ND NODE)
RIGHT KNEE (3RD NODE)
LEFT KNEE (4TH NODE)
RIGHT HAND (5TH NODE)
LEFT HAND (6TH NODE)
FOOT GROUP (12TH NODE)
KNEE GROUP (34TH NODE)
LEG GROUP (1234TH NODE)
HAND GROUP (56TH NODE)
ENTIRE GROUP (123456TH NODE)

FIG.62

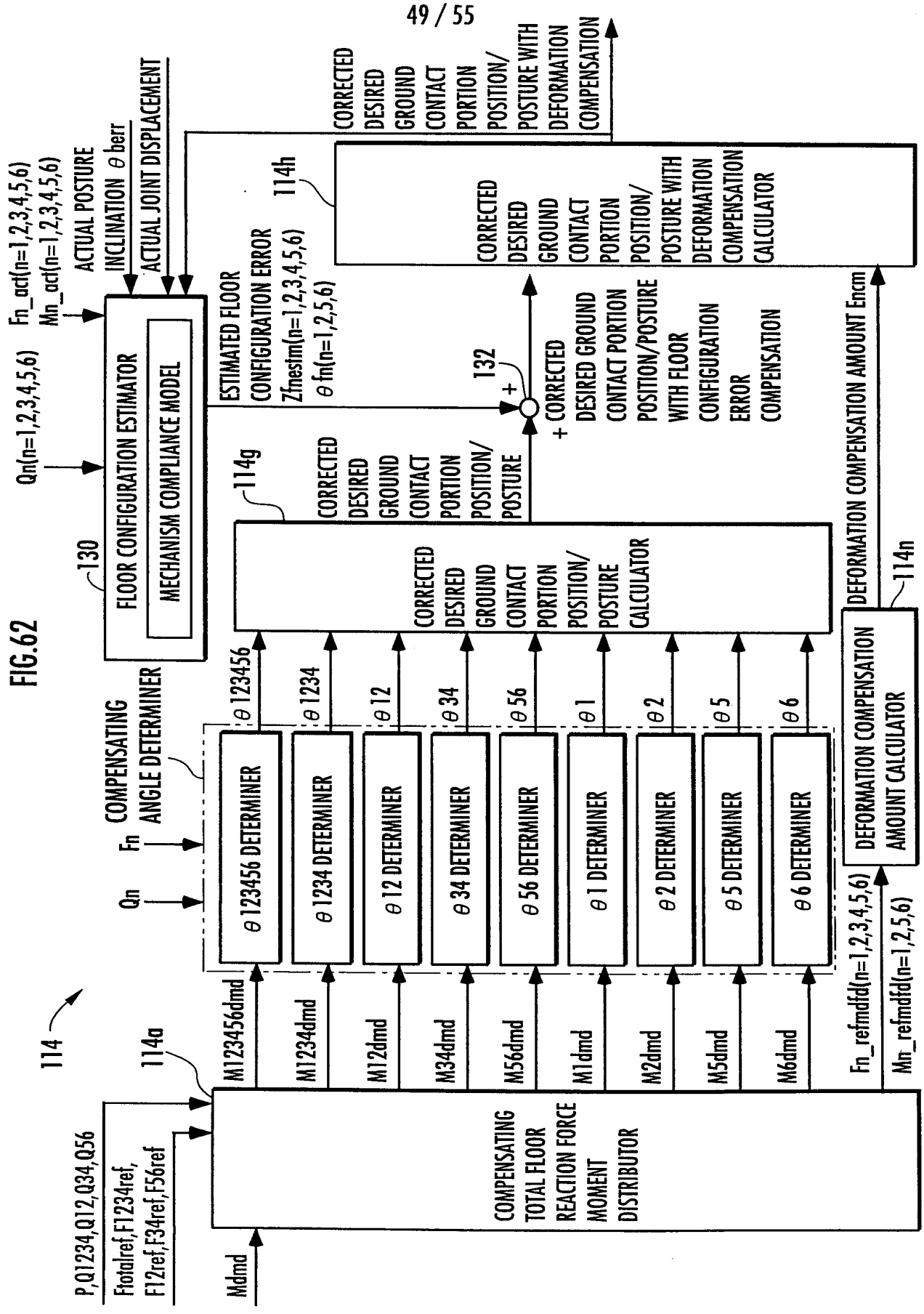

P,Q1234,Q12,Q34,Q56
Ftotalref,F1234ref,
F12ref,F34ref,F56ref
Mdmd
114
114a
COMPENSATING TOTAL FLOOR REACTION FORCE MOMENT DISTRIBUTOR
M123456dmd
M1234dmd
M12dmd
M34dmd
M56dmd
M1dmd
M2dmd
M5dmd
M6dmd
Fn_refmdfd(n=1,2,3,4,5,6)
Mn_refmdfd(n=1,2,5,6)
DEFORMATION COMPENSATION AMOUNT CALCULATOR
114n
DEFORMATION COMPENSATION AMOUNT Encm
θ 123456 DETERMINER
θ 1234 DETERMINER
θ 12 DETERMINER
θ 34 DETERMINER
θ 56 DETERMINER
θ 1 DETERMINER
θ 2 DETERMINER
θ 5 DETERMINER
θ 6 DETERMINER
θ 123456
θ 1234
θ 12
θ 34
θ 56
θ 1
θ 2
θ 5
θ 6
COMPENSATING ANGLE DETERMINER
Qn
Fn
CORRECTED DESIRED GROUND CONTACT PORTION POSITION/ POSTURE CALCULATOR
114g
CORRECTED DESIRED GROUND CONTACT PORTION POSITION/ POSTURE
132
+
+ CORRECTED DESIRED GROUND CONTACT PORTION POSITION/POSTURE WITH FLOOR CONFIGURATION ERROR COMPENSATION
CORRECTED DESIRED GROUND CONTACT PORTION POSITION/ POSTURE WITH DEFORMATION COMPENSATION CALCULATOR
114h
CORRECTED DESIRED GROUND CONTACT PORTION POSITION/ POSTURE WITH DEFORMATION COMPENSATION
ESTIMATED FLOOR CONFIGURATION ERROR
Zfnestm(n=1,2,3,4,5,6)
θ fn(n=1,2,5,6)
130
FLOOR CONFIGURATION ESTIMATOR
MECHANISM COMPLIANCE MODEL
Qn(n=1,2,3,4,5,6)
Fn_act(n=1,2,3,4,5,6)
Mn_act(n=1,2,3,4,5,6)
ACTUAL POSTURE INCLINATION θ berr
ACTUAL JOINT DISPLACEMENT

FIG.63(a)

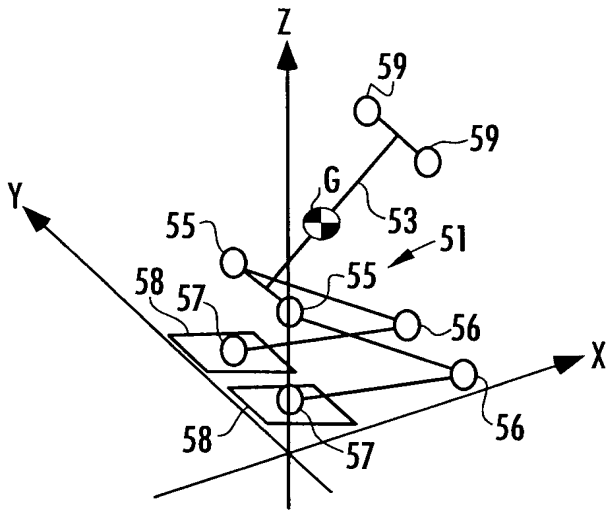


FIG.63(b)

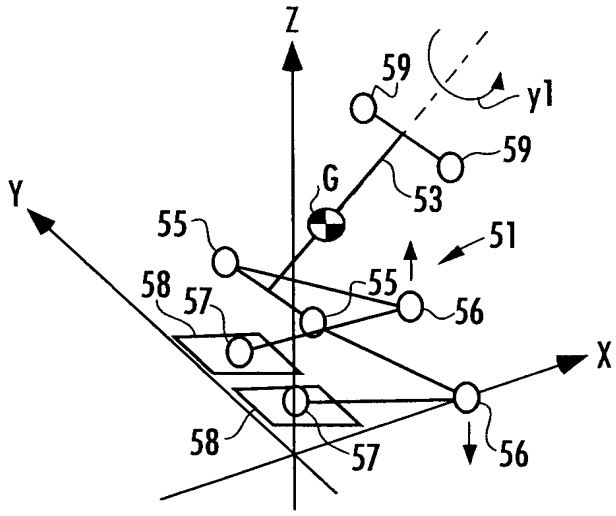


FIG.63(c)

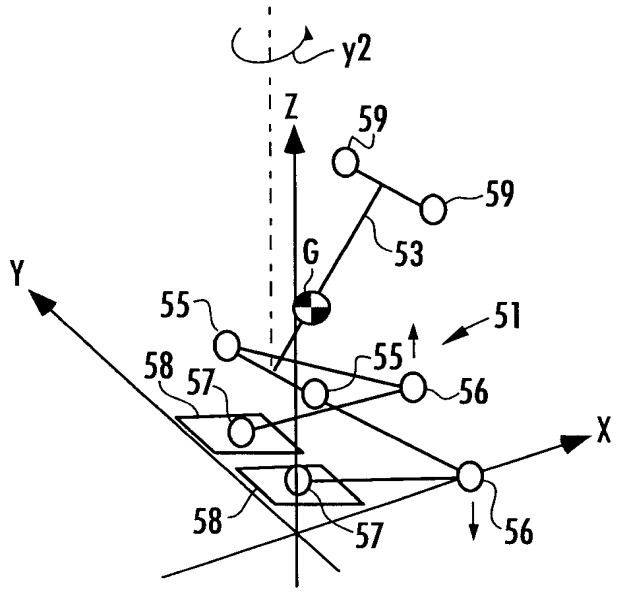


FIG.64

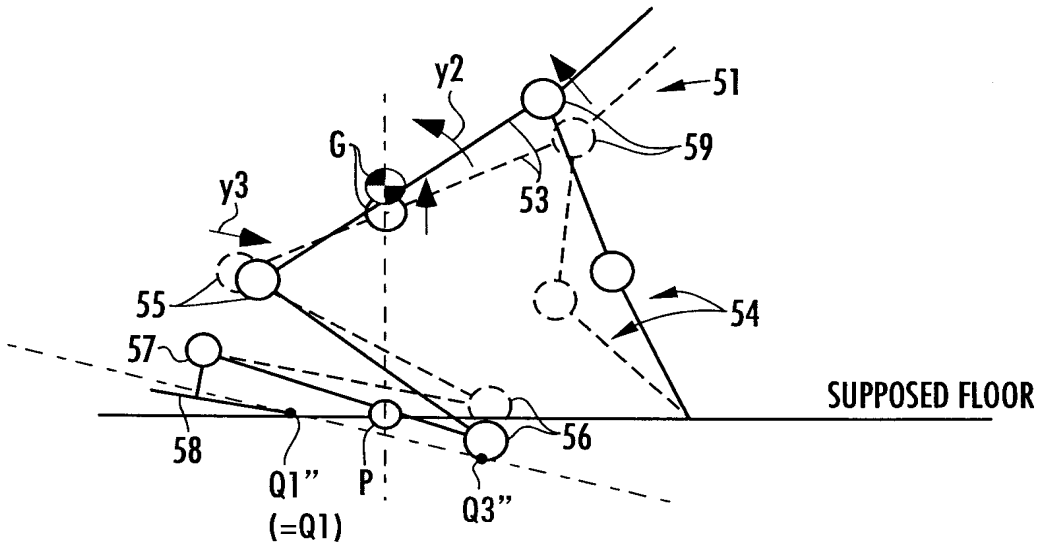


FIG.65

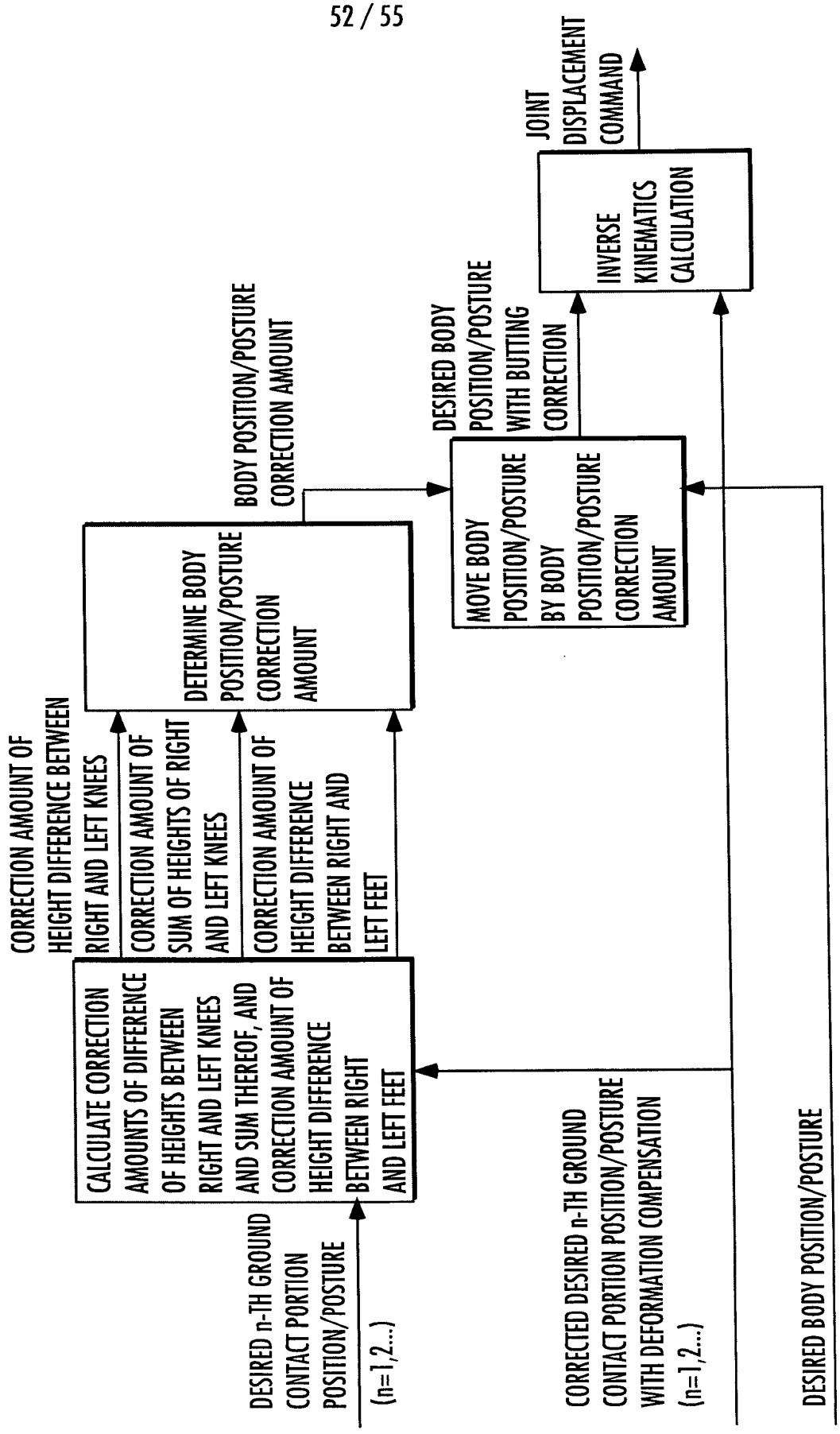

DESIRED n-TH GROUND CONTACT PORTION POSITION/POSTURE (n=1,2...)
CALCULATE CORRECTION AMOUNTS OF DIFFERENCE OF HEIGHTS BETWEEN RIGHT AND LEFT KNEES AND SUM THEREOF, AND CORRECTION AMOUNT OF HEIGHT DIFFERENCE BETWEEN RIGHT AND LEFT FEET
CORRECTION AMOUNT OF HEIGHT DIFFERENCE BETWEEN RIGHT AND LEFT KNEES
CORRECTION AMOUNT OF SUM OF HEIGHTS OF RIGHT AND LEFT KNEES
DETERMINE BODY POSITION/POSTURE CORRECTION AMOUNT
BODY POSITION/POSTURE CORRECTION AMOUNT
MOVE BODY POSITION/POSTURE BY BODY POSITION/POSTURE CORRECTION AMOUNT
DESIRED BODY POSITION/POSTURE WITH BUTTING CORRECTION
INVERSE KINEMATICS CALCULATION
JOINT DISPLACEMENT COMMAND
CORRECTED DESIRED n-TH GROUND CONTACT PORTION POSITION/POSTURE WITH DEFORMATION COMPENSATION (n=1,2...)
DESIRED BODY POSITION/POSTURE

FIG.66

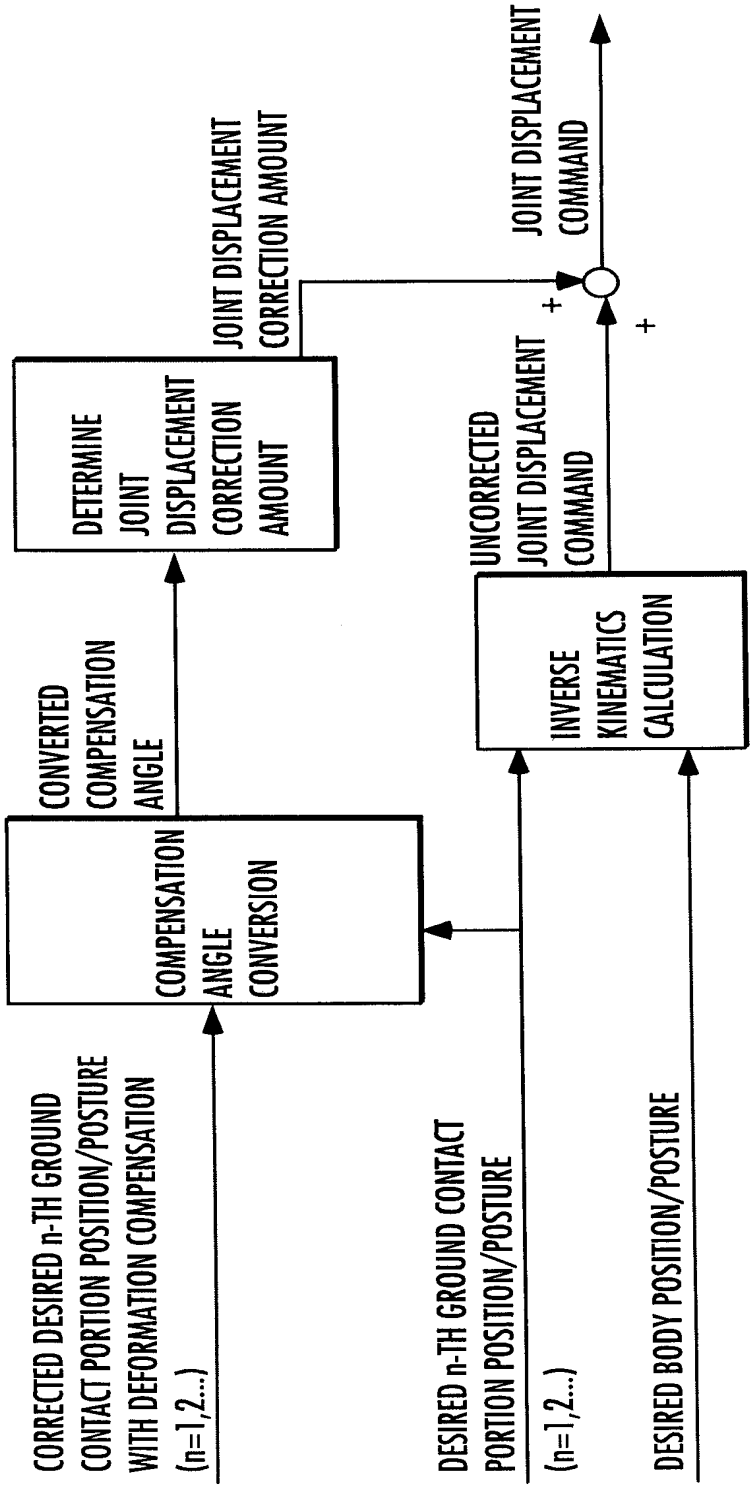

CORRECTED DESIRED n-TH GROUND CONTACT PORTION POSITION/POSTURE WITH DEFORMATION COMPENSATION (n=1,2...)
DESIRED n-TH GROUND CONTACT PORTION POSITION/POSTURE (n=1,2...)
DESIRED BODY POSITION/POSTURE
COMPENSATION ANGLE CONVERSION
INVERSE KINEMATICS CALCULATION
CONVERTED COMPENSATION ANGLE
UNCORRECTED JOINT DISPLACEMENT COMMAND
DETERMINE JOINT DISPLACEMENT CORRECTION AMOUNT
JOINT DISPLACEMENT CORRECTION AMOUNT
JOINT DISPLACEMENT COMMAND
+
+

FIG.67

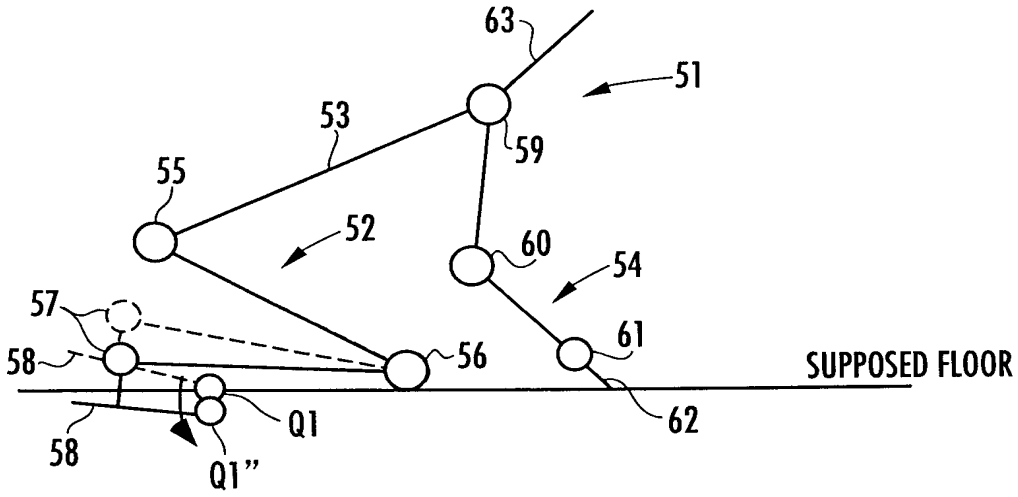

63
51
53
59
55
52
60
54
57
61
58
56
SUPPOSED FLOOR
Q1
62
58
Q1"

FIG.68

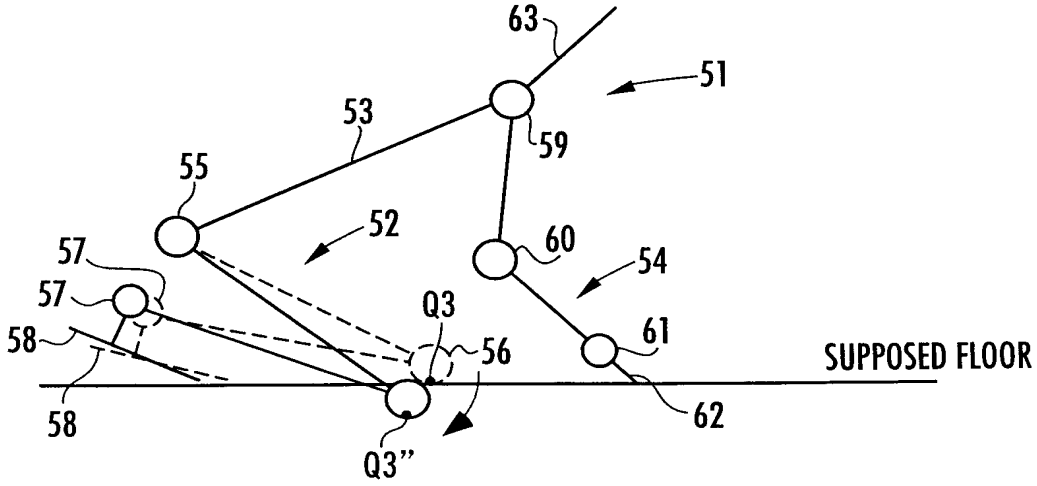

63
51
53
59
55
52
60
54
57
57
Q3
61
58
56
SUPPOSED FLOOR
58
62
Q3"

FIG.69

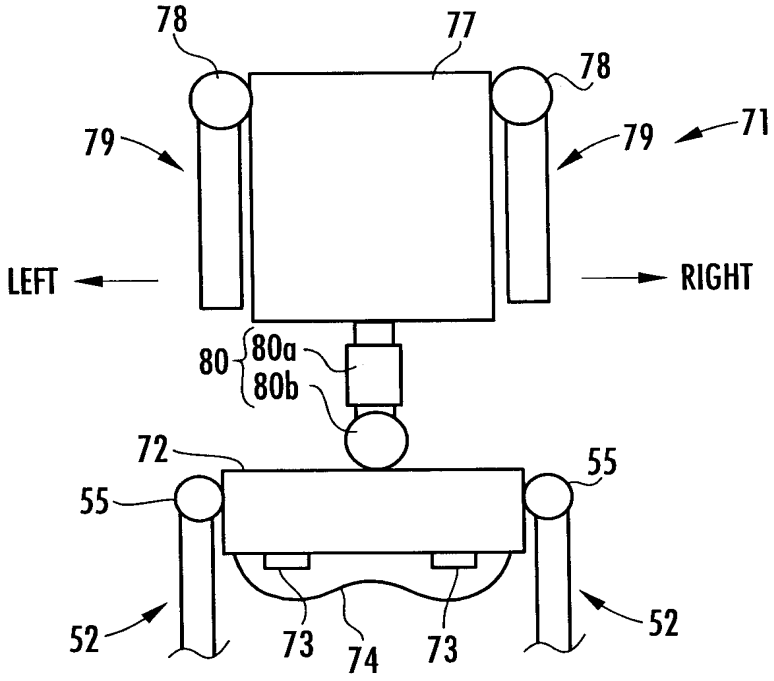
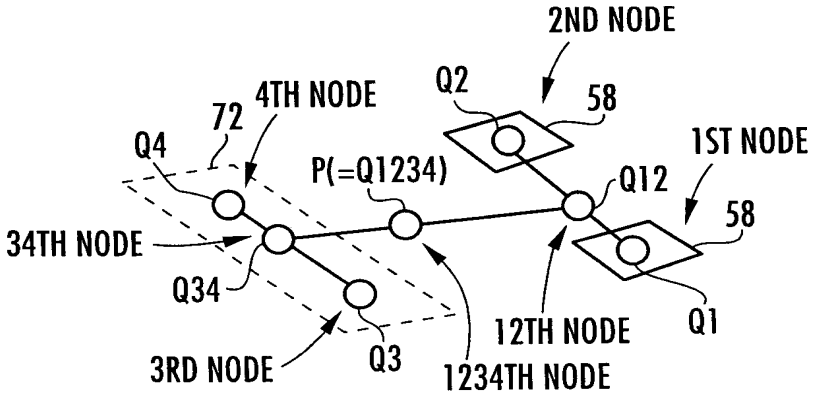

78
77
78
79
79
71
LEFT
RIGHT
80
80a
80b
72
55
55
52
52
73
74
73

FIG.70


2ND NODE
Q2
58
4TH NODE
72
Q4
1ST NODE
P(=Q1234)
Q12
58
34TH NODE
Q34
Q1
12TH NODE
3RD NODE
Q3
1234TH NODE